Contact Lens Dynamometry: The Influence of Age

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Purpose. To examine the influence of age on systolic (systOAP) and diastolic (diastOAP) blood pressure in the ophthalmic artery (OA) measured with a new contact lens dynamometer (CLD).

Methods. In a prospective cross-sectional clinical trial, 106 eyes of 106 patients (58 women, 48 men) were examined. A nearly uniform age distribution was achieved by recruiting subjects in seven age groups, with at least 12 in each decade. Blood pressure in the OA was measured with a new CLD. Arterial blood pressure at the upper arm was measured by cuff, according to the Riva-Rocci (RR) method. Main outcome measures were: systOAP and diastOAP in the OA and systolic (systRR) and diastolic (diastRR) pressures in the subclavian artery.

Results. The blood pressures showed the following linear regression equations in association with age: systRR (mm Hg) = 115 + 0.45 × age (years) (R = 0.50; P < 0.00001); diastRR (mm Hg) = 72 + 0.28 × age (years) (R = 0.42; P < 0.00001); systOAP (mm Hg) = 61 + 0.93 × age (years) (R = 0.74; P < 0.0001); and diastOAP (mm Hg) = 44 + 0.37 × age (years) (R = 0.57; P < 0.0001).

Conclusions. The relative slopes of the regression lines relating age to diastolic and systolic pressures are steeper in the ophthalmic than in the subclavian artery, indicating that the pressures in the ophthalmic artery increase faster with age than do the associated pressures in the subclavian artery, as measured by the standard sphygmomanometer. This phenomenon may be explained by progressive stiffening of the walls in the carotid and ophthalmic arteries. The effect of age should be taken into account whenever interpreting ophthalmodynamometric measurements for clinical diagnostic purposes. (Invest Ophthalmol Vis Sci. 2010;51:6620–6624) DOI:10.1167/iovs.09-4594

Ophthalmodynamometry is a method of measuring blood pressure in the ophthalmic artery.1-3 From the biophysical point of view, ophthalmodynamometry is accomplished via iatrogenic elevation of intraocular pressure (IOP) by the application of force on the globe, allowing dynamic observation of the pulsation of vessels entering and exiting the eye at the optic disc. Usually in ophthalmodynamometry the arterial pressures are measured. However, it is also possible but not widely known that the venous pressure can be measured as described by Meyer-Schwickerath et al.4 Recent results showed that increased pressure in the central retinal vein may play a role in the pathogenesis of glaucoma.5-9 Initial attempts to use ophthalmodynamometry clinically involved methods of determining incremental IOP increase by using compressive spring loading1 or sclera-deforming suction cups.10 The level of the artificially elevated IOP was correlated experimentally with the applied force, and conversion tables were established. From these tables, the force needed to initiate the pulsation was converted to IOP.11 As these techniques were often difficult to perform and the use of correlation tables was cumbersome and introduced potential sources of error, most have been almost abandoned in clinical practice. More recently introduced contact lens methods applying mechanical force and semiautomated pressure measurement12-15 failed to gain favor and were generally considered too cumbersome.16 These techniques were predominantly used as diagnostic tests in suspected carotid artery stenosis, until they were superseded by the advent of Doppler ultrasound sonography.

An important practical advance from the physical point of view was the Smartlens (ODC Ophthalmic Development Company, Zürich, Switzerland), the first electronic contact lens dynamometer (CLD),15,16 which allowed direct measurement of artificially elevated IOP. Even this instrument required substantial expertise and was not widely adopted clinically.

Recently, a new electronic CLD was introduced that allows more straightforward application of ophthalmodynamometry in clinical practice. Jonas et al.17-32 have demonstrated the potential of this new CLD in the diagnostics of circulatory diseases of the eye, orbit, and brain. The purpose of the present study was to examine the effect of age on measurements obtained with this new electronic CLD.

Methods

In this prospective clinical trial, 106 volunteers (Table 1) were included. Each subject signed an informed consent before entering the study. The study was performed in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee of the Medical Faculty of the University of Dresden.

Exclusion criteria were diabetes mellitus, arterial hypertension, cardiovascular diseases, peripheral arterial and venous diseases, all types of glaucoma, eye surgery (except phacoemulsification more than 3 months ago), circulation diseases of the eye and the brain, and systemic therapy with calcium channel blockers and/or β-blockers.

Description of the CLD

The CLD (Meditron GmbH, Völklingen, Germany) is FDA approved. It consists of a commercially available Goldmann three-mirror contact lens that is mounted to a metal ring (Fig. 1). At the junction of these two parts, strain gauges are placed with a maximum spatial dislocation under clinical conditions of 10 μm. The signals of the strain gauges are led from the metal ring to the indicating instrument by a flexible cable and are converted to IOP increase in millimeters of mercury (mm Hg). This conversion is based on the results of concomitant manometrically monitored animal experiments and on a direct comparison with results...
obtained by the Smartlens in humans.\textsuperscript{33} The actual pressure in the eye under force application is calculated as the sum of the pressure increase and the IOP measured before the application of the CLD.

**CLD Examination Procedure**

The subjects were seated with chin and forehead positioned against their respective rests on a slit lamp biomicroscope (Haag-Streit, K\öni\z, Switzerland) set at 16-fold magnification. Before each measurement, the offset of the instrument was set to 0 according to the routine described in the manual. The reading of the LCD-display indicated pressure increase in mm Hg. The actual pressure at which the pulsation phenomena were observed was the sum of the measured pressure increase and the IOP measured by applanation tonometry immediately preceding the CLD procedure.

**Examination Procedure**

One randomly chosen eye of each subject was examined. Initially the biomechanical properties of the cornea were measured (Ocular Response Analyzer; Reichert, Depew, NY) along with optical biometry (IOL Master; Carl Zeiss Meditec, Inc., Jena, Germany). Then, one drop proxymetacaine (Proparacaine POS 0.5%; Ursapharm, Saarbrüken, Germany) was applied for topical anesthesia, and central corneal thickness (CCT) was measured by ultrasound pachymetry (IOPac CCT-Pachymeter; Heidelberg Engineering, Heidelberg, Germany). Subsequently the pupils were dilated by one drop tropicamide (Mydrum; Chauvin Anker, Berlin, Germany) and the result was noted. The criterion was a clearly detectable pulsation. After instillation of one drop oxybuprocaine-HCl with fluorescein (Thilorbin; Alcon, Freiburg, Germany), applanation tonometry was performed (Haag-Streit) with later correction for central corneal thickness, according the Dresden table\textsuperscript{34} (corrected IOP in mm Hg).

Systemic (RR) blood pressure was automatically measured by the Riva-Rocci method (M5 Professional; Omron, Mannheim, Germany) 1 minute before placing the CLD and then during and 2 minutes after the procedure. One drop of proxymetacaine (ProparakainPOS 0.5%; Ursapharm) for topical anesthesia was applied before placement of the CLD. Hypromellose ( Methocel 2%; CIBA Vision, Grossostheim, Germany) was used as the contact fluid.

After the placement of the CLD, the optic nerve head was brought into sight. The compressive force was increased until the first unequivocal pulsation of the central retinal artery\textsuperscript{10} was seen. Corneal compression was then reduced until the pulsation disappeared, and the pressure at this moment was noted as the diastolic pressure. This measurement was taken three times. Then, the force was rapidly enhanced further until the pulsation of the central retinal artery stopped. Compression was reduced until the pulsation started again, similar to the Riva-Rocci method. The descending threshold pressure at this moment was noted as the systolic pressure. This measurement was performed only once. The actual pressures were obtained during each measurement by adding the IOP measured before the CLD procedure to the arithmetic mean of the preprocedure IOP measurement. These sums of IOP plus diastolic and IOP plus systolic pressures were entered into the database.

**Statistics and Estimation of the Sample Size**

Statistical evaluation was performed using univariate and multivariate linear regression analyses (SPSS, ver. 15.0; SPSS GmbH Software, Munich, Germany, or Statistica, ver. 7; StatSoft Inc., Tulsa, OK). The sample size was estimated according to the equation \( N \geq 50 + 8m \), where \( m \) is the desired number of predictors.\textsuperscript{35} With six predictors age, systolic RR, diastolic RR, heart rate, IOP, and sex, more than 98 subjects were needed.

Equal distribution was achieved in the seven age groups by including approximately 15 participants per decade, with \( N = 106 \) eyes of 106 subjects (\( x \) right eyes and \( y \) left eyes).

**RESULTS**

The age classes and the number of subjects in each class, sex, age, and systemic blood pressure are given in Table 1. Table 2 shows the blood pressure in the ophthalmic artery measured by CLD. The pressure values in Table 2 are the sum of the pressure increase measured by CLD and the mean CCT-corrected IOP.

The best correlation of the ophthalmic artery pressure (CLD) with the systemic blood pressure (RR; Fig. 2) was ob-

![Figure 1. Measurement with the CLD.](image-url)
tained when the measurements of the systemic blood pressure were obtained simultaneously with CLD (systole: \( R^2 = 0.63 \); diastole: \( R^2 = 0.49 \)).

Among the study population, systolic CLD (\( R^2 = 0.55 \); see Fig. 2, left), the diastolic CLD (\( R^2 = 0.32 \); see Fig. 2, right), systolic RR (\( R^2 = 0.25 \), Fig. 2, left), and diastolic RR (\( R^2 = 0.17 \), Fig. 2, right) all showed a statistically significant increase with age. The increase in blood pressure with age was higher in the ophthalmic artery than in the subclavian artery. This effect was more pronounced for systolic CLD pressure. Multivariate regression analysis showed that the diastolic CLD pressure was dependent on age, diastolic systemic RR, and sex (\( R^2 = 0.578 \)). Systolic CLD pressure was dependent on age and systolic RR (\( R^2 = 0.787 \)).

The factor by which the RR pressure has to be multiplied to get the expected pressure in the ophthalmic artery in healthy subjects is provided in Figure 3. For comparison, the previous assumption is graphically shown as a horizontal dashed line. For practical purposes, nomograms for systolic and diastolic measurements are given (Figs. 4).

**DISCUSSION**

Ophthalmodynamometry measures the pressure in the ophthalmic artery near the branching of the central retinal artery and not in the central retinal artery, as assumed at first by Bailliart. According to the principle of the Pitot static tube, the point of measurement is not at the place where the pulsation phenomenon is observed, but at the nearest proximal bifurcation where the blood can flow freely away via alternative anastomotic pathways. In the case of the central retinal artery pulsation, the relevant place of measurement is in the ophthalmic artery. Accordingly, for the measurement of the brachial systemic blood pressure (Riva-Rocci method) the relevant point of measurement is not the upper arm where the cuff is placed but the subclavian artery. (For simplification, we have used the term RR for the subclavian artery pressure and the term CLD for the pressure in the ophthalmic artery.)

The arterial blood pressure measured at the eye has hitherto been considered to be dependent on systemic blood pressure. It was thus considered necessary to measure systemic blood pressure, in addition to the pressure measurement in the ophthalmic artery by CLD, in the search of stenoses in the carotid arteries. Our systolic and diastolic RR values are listed in Table 1. The increase with age is in agreement with the data of Kaplan. The observed increase of the arterial CLD values with age (Table 2, Fig. 2) is partially associated with the increase in the systemic blood pressure.

**TABLE 2. Contact Lens Dynamometry**

<table>
<thead>
<tr>
<th>Age Group (y)</th>
<th>Systolic (mm Hg)</th>
<th>Diastolic (mm Hg)</th>
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<tr>
<td></td>
<td>Min</td>
<td>Med</td>
</tr>
<tr>
<td>10–19</td>
<td>56</td>
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<td>&gt;69</td>
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<td>121</td>
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**FIGURE 2.** Scatterplot of the subclavian artery pressure (RR) (black symbols) and ophthalmic artery pressure measured by CLD (gray symbols) plotted versus the age of the subjects. Also displayed is the coefficient of determination (\( R^2 \)). Left: systolic; right: diastolic.

**FIGURE 3.** The ratio by which the ophthalmic artery pressure measured by CLD is lower than the pressure in the subclavian artery measured with the cuff (RR) is plotted versus the age of the subjects. The previous assumption is shown as a dashed horizontal line. Solid line: ratio in systolic values; dotted line: ratio in diastolic values; broken line: ratio in systolic and diastolic values previously assumed.

**FIGURE 4.** Nomograms facilitating the reading of the estimated ophthalmic artery pressure in a healthy subject at a given subclavian artery pressure measured by the cuff method (RR). Oblique lines: the expected ophthalmic artery pressure at a given subclavian artery pressure measured by the cuff method (RR). The lines are shown at intervals of 10 mm Hg RR (the scale at the right origin of the oblique lines represents the measured RR pressure of the patient). To determine the ophthalmic artery pressure, a vertical line is drawn at the age of the patient. The expected ophthalmic artery pressure is read off as the ordinate value of the intersection of the vertical line with the line for the measured RR pressure of the patient.
Figure 2 shows that the systolic CLD pressures rose faster with age than did the systolic RR pressures. This behavior may be explained by the increasing rigidity\(^{39}\) of the walls of the peripheral arteries with age. It is possible that this effect is more pronounced in the carotids and their branches than in the subclavian artery.

With diastolic values, the increase with age is less pronounced in the RR pressures than in the CLD values. In both instances, the increase with age is less pronounced than that of the corresponding systolic pressures.

The findings shown in Figure 2 suggest that the recommendations of Weigelin and Lobstein\(^3\) and of Ulrich\(^10\) (multiplication of the RR values by 0.67) for the calculation of the blood pressure in the ophthalmic artery may have to be amended, as they made their predictions without consideration of age (Fig. 3). This adjustment may be very important clinically, as the calculation of perfusion pressures from RR pressures in older patients may be expected to result in falsely lower values, misleadingly suggesting that the perfusion pressure is too low. As suggested in Figure 3, normative values should probably be based on measurements in subjects of the same age class. As mentioned, Ulrich\(^10\) based his recommendations on subjects predominantly under the age of 40. Given our present findings, we suggest that the systolic and diastolic blood pressures in the ophthalmic artery should be calculated according to Figure 3 or read from nomograms (Fig. 4).

In the multivariate linear regression analysis, the CLD showed the highest statistically significant dependence of RR values and age. When the CLD pressures were calculated by the resulting formula, the results were practically the same as in Figure 4:

\[
\text{Systolic ophthalmic artery pressure} = 0.744 \times \text{systolic RR} + 0.575 \times \text{age} - 23.93 (R^2 = 0.787; P = 0.0001) \\
\text{Diastolic ophthalmic artery pressure} = 0.707 \times \text{diastolic RR} + 0.218 \times \text{age} - 7.53 (R^2 = 0.578; P = 0.0001)
\]

The sex of the subjects was not included in the formula for the calculation of diastolic values for the sake of simplicity. The inclusion of sex would increase \(R^2\) by 0.036 and the diastolic pressure would be 5 mm Hg higher in the men than in the women.

For practical purposes, nomograms for systolic and diastolic measurements are given (Fig. 4). These nomograms allow an estimation of the pressure in the ophthalmic artery to be made in healthy subjects by using age and RR.

In clinical diagnostics the measured CLD pressures are compared with the calculated values, and differences may hint at pathologic conditions. Considering the influence of age should improve the specificity of ophthalmodynamometry and thus reduce the false-positive rate in the diagnosis of carotid stenosis.

In conclusion, age is positively associated with the pressure in the subclavian artery as measured by the Riva-Rocci method, and to an even greater extent and with a more pronounced gradient, with the pressure in the ophthalmic artery as measured by CLD. Both the systolic and diastolic ophthalmic artery pressures become higher in relation to corresponding subclavian artery pressures with aging. This effect may be explained by disproportionately increasing stiffness of the carotid vessels and the ophthalmic artery\(^{39,40}\) with age. Diagnostic recommendations given on the basis of earlier methods of ophthalmodynamometry may have to be revised accordingly to account for this effect of aging.

References