

Effects of change in intraocular pressure on axial eye length and lens position

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CLINICAL STUDY

Abstract

Purpose To quantify the biometric changes of ocular dimensions with mechanical elevation of intraocular pressure (IOP) *in vivo*, to get a better understanding of the elastic properties of the human ocular structures that may play a role in the pathogenesis of various diseases such as myopia or glaucoma.

Methods Changes in IOP were induced by a suction cup in 18 eyes under cycloplegia. Axial eye length (AEL) and anterior chamber depth (ACD) were measured with non-invasive laser interferometry during elevation of the IOP 10 and 20 mmHg over baseline values and after a 10-min resting period.

Results IOP elevation of 10 and 20 mmHg respectively caused a significant increase of AEL of 23 μm (95% confidence interval: 14–34 μm) and 39 μm (confidence interval (CI): 28–51 μm). After mechanical oculopression, which resulted in an IOP reduction of –5.1 mmHg (CI: –6.3 to –4.0 mmHg) *vs* baseline, a significant shortening of –7 μm (CI: –13 to 0 μm) was observed. The change in AEL correlated with the change in IOP ($r = 0.66$, $P = 0.005$). Furthermore, a significant increase in ACD of 30 μm (CI: 24–36 μm) was detected with IOP reduction after oculopression, but no change was seen during IOP elevation.

Conclusions Biometric changes of the human eye as a response to IOP changes were assessed *in vivo*. The correlation between change in AEL and IOP found emphasizes the need of *in vivo* ocular rigidity measurements in the human eye.

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Keywords: intraocular pressure; axial eye length; ocular rigidity

Introduction

Intraocular pressure (IOP) plays an important role in the pathogenesis of glaucoma and has been hypothesized to be one of several factors implicated in the pathogenesis of myopia and age-related macular degeneration. Elevated IOP was assumed to impose scleral stress and creep, resulting in axial eye elongation with scleral stretch.¹ Several studies have evaluated the relation between IOP and myopia development (predominantly in children and animal models) with controversial results: some studies reported a positive association,^{2–4} whereas others found no relation between IOP and myopia.^{5–7} However, the nature and extent of the influence of IOP on eye growth remain poorly understood.

Rather than IOP, ocular rigidity is thought to play an important role in the pathogenesis of myopia. The human sclera was found to be related to the refractive status insofar that scleral rigidity was lower in myopes than non-myopes.⁸ Other studies, however, revealed a poor correlation between the degree of myopia and ocular rigidity.^{9,10} A recent study demonstrated a positive correlation between ocular rigidity and age of patients, whereas there was no correlation between ocular rigidity and axial eye length.¹¹

In a previous study, a shortening of axial eye length by 46 μm was found with pharmacological IOP reduction (Kiss B *et al.* IOVS 1999; ARVO abstract 2379). However, it is unclear as to how far the pharmacological agent used, in that case the antiglaucomatous drug timolol, directly influenced choroidal thickness and therefore axial eye length.

The aim of this study was to investigate the effect of short-term mechanical IOP elevation and the effect of oculopression on ocular dimensions in emmetropic eyes.

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Material and methods

All the research and measurements followed the tenets of the Helsinki agreement. Informed consent was obtained from all subjects in this study after the nature and possible consequences of the study had been explained. The study was approved by the ethics committee of the Medical University of Vienna.

Eighteen eyes of 18 healthy subjects (mean age: 25 years range: 19–29 years) were included in this open pilot study. All subjects had a spherical equivalent (SE) refractive error of less than ±0.5D and no history of ocular disease, trauma, or surgery. None of the subjects used topical or systemic medications. Before inclusion, a complete ophthalmic examination including a retinal examination after pupil dilatation was performed. Intraocular pressure was measured by Goldmann tonometry and refractive error was measured under cycloplegia with an autorefractometer (Zeiss Humphrey Automatic Refraktometer Model 597, Zeiss Meditec, Jena, Germany).

Axial eye length (AEL), defined as the distance from the anterior corneal surface to the retinal pigment epithelium, was measured with the IOL Master (Zeiss Meditec, Jena, Germany) using partial coherence laser interferometry (PCI). The principle of this biometry technique has been described in detail previously.^{12–14} A novel commercially available interferometer, the AC Master (Zeiss Meditec, Jena, Germany), that is based on the same measurement principle was used to measure central corneal thickness (CCT), anterior chamber depth (ACD), and lens thickness (LT). CCT was defined as the distance from the anterior corneal surface to the posterior corneal surface, ACD as the distance from the anterior corneal surface to the anterior lens surface, and LT as the distance from the anterior lens surface to the posterior lens surface. Eight to ten measurements of AEL, CCT, ACD, and LT were taken in each situation for statistical purposes.

Data are presented as mean value ±95% confidence interval (CI). The precision of PCI is defined as the SD of multiple recorded consecutive measurements of the ocular distance under investigation. The Student’s *t*-test

for related samples was used to compare the means, considering *P* < 0.05 for statistical significance.

Intraocular pressure was increased by means of the episcleral suction cup technique.¹⁵ With this technique, a suction cup (diameter 11 mm) is applied to the temporal sclera just posterior to the limbus. It produces a negative pressure that is transferred onto the globe and induces a subsequent increase in IOP. In the present study, a suction pressure of 10 and 20 mmHg was applied. A Perkins handheld applanation tonometer (MK 2, Clement Clarke, England) was used to measure IOP. Before each measurement, one drop of oxybuprocaine with fluorescein (Flurekain ‘Croma’, Croma-Pharma, Austria) was instilled into the conjunctival sac for local anaesthesia.

Baseline measurements of AEL, CCT, ACD, LT, and IOP were performed 30 min after instillation of two drops of cyclopentolate (cyclopentolate 1%, ‘Thilo’, Alcon, Austria). Thereafter, the IOP was first increased by 10 mmHg and then again by 20 mmHg over baseline IOP. At each step, the artificially induced increase in IOP was maintained for 5 min plus the time required to complete biometric measurement (not exceeding a total time of 8 min). The IOP was controlled by scleral suction and monitored by applanation tonometry. Ten minutes after the last intervention period, measurements were repeated. These served as measurements after oculopression.

Results

Absolute values of biometric variables and IOP at baseline and ‘suction cup-induced’ increases of 10 and 20 mmHg, as well as after oculopression, are given in Table 1.

Elevating the IOP 10 and 20 mmHg above baseline resulted in significant increases of AEL by 23 µm (95% CI: 14–34 µm, *P* < 0.001) and 39 µm (CI: 28–51 µm, *P* < 0.001), respectively (Figure 1). Ten minutes after removal of the suction cup, AEL shortened by –7 µm (CI: –13 to 0 µm, *P* < 0.05) whereas the IOP decreased by –5.1 mmHg (CI: –6.3 to –4.0 mmHg, *P* < 0.005) compared

Table 1 Data of AEL, CCT, ACD, LT in mm and IOP in mmHg at baseline, at IOP elevations of 10 and 20 mmHg and after oculopression presented as mean value ±95% confidence interval

	Baseline	IOP Elevation + 10 mmHg	IOP Elevation + 20 mmHg	IOP after oculopression
AEL	23.214 (22.553–24.255)	23.236 (22.600–24.259)	23.253 (22.587–24.259)	23.207 (22.539–24.237)
CCT	0.520 (0.498–0.543)	0.519 (0.497–0.541)	0.519 (0.496–0.541)	0.522 (0.501–0.544)
ACD	3.716 (3.295–4.043)	3.716 (3.294–4.064)	3.719 (3.298–4.072)	3.744 (3.333–4.090)
LT	3.694 (3.141–4.263)	3.703 (3.324–4.296)	3.705 (3.348–4.279)	3.700 (3.310–4.278)
IOP	14 (11–17)	24 (18–28)	34 (32–36)	8 (5–14)

ACD, anterior chamber depth; AEL, axial eye length; CCT, central corneal thickness; IOP, intraocular pressure; LT, lens thickness.

to baseline values. There was a significant correlation of 0.66 ($P < 0.005$) between the decrease of IOP with the decrease of AEL after oculopression (Figure 2, left graph).

The ACD did not change significantly during pressure elevation of 10 and 20 mmHg, ($2 \mu\text{m}$, CI: -2 to $7 \mu\text{m}$, $P = 0.33$ and $5 \mu\text{m}$, CI: 0 – $11 \mu\text{m}$, $P = 0.09$) (Figure 3). However, with IOP reduction after suction cup removal, there was a significant increase in ACD of $30 \mu\text{m}$ (CI: 24 – $36 \mu\text{m}$, $P < 0.001$) compared to baseline. The correlation between the decrease of IOP and increase of

ACD was 0.49 ($P < 0.05$) (Figure 2, right graph). ACD changes were not related to a change in LT that showed small, not clinically relevant changes. Also CCT did not change significantly at any time.

The precision for AEL measurements as assessed with the IOL Master was $15 \mu\text{m}$ (range: 9 – $23 \mu\text{m}$), whereas the precision for CCT, ACD, and LT measurements as assessed with the AC Master was $1.3 \mu\text{m}$ (range: 0.7 – 1.9), $3.8 \mu\text{m}$ (range: 1.5 – $7.6 \mu\text{m}$), and $3.2 \mu\text{m}$ (range: 1.4 – $6.4 \mu\text{m}$), respectively.

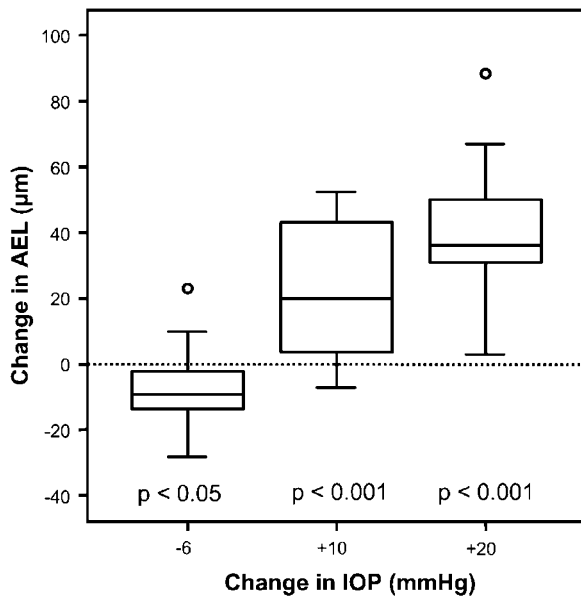


Figure 1 Change in AEL at different IOP values compared to baseline. Negative values indicate a shortening; positive values an elongation of axial eye length. Boxes indicate the interquartile range, whiskers the non-outlier minimum and maximum, and the line in the box represents the median. Outliers (defined as values outside the 1.5 box length range from the upper and lower value of the box) are represented by circles.

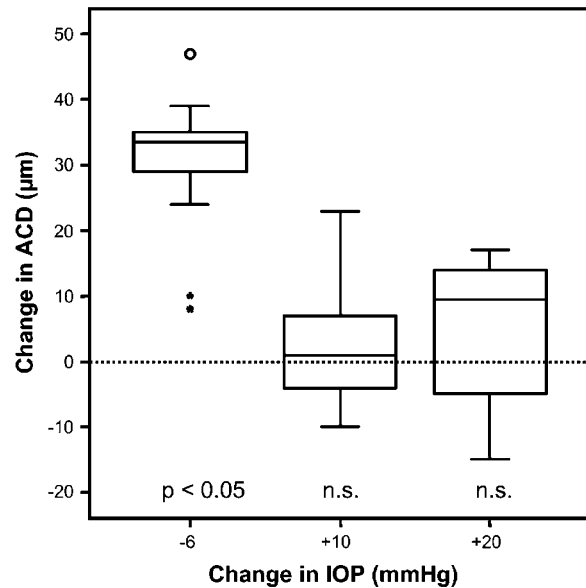


Figure 3 Change in ACD at different IOP values compared to baseline. Negative values indicate a decrease; positive values an increase of ACD. Boxes indicate the interquartile range, whiskers the non-outlier minimum and maximum, and the line in the box represents the median. Outliers (defined as values outside the 1.5 box length range from the upper and lower value of the box) are represented by circles, and extreme values (defined as values outside the 3 box length range from the upper and lower value of the box) by stars.

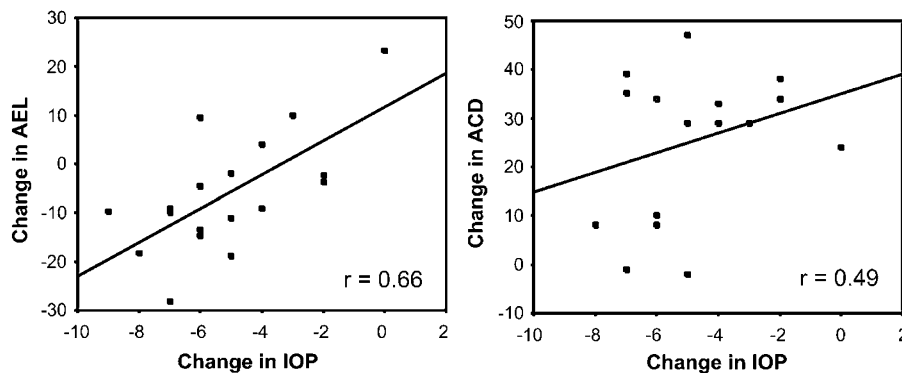


Figure 2 Correlation of change in AEL (left graph) and change in ACD (right graph) with change in IOP after oculopression. The line represents the linear regression line (AEL: $r = 0.66$, $P < 0.005$; ACD: $r = 0.49$, $P < 0.05$).

Discussion

With short-term elevation of IOP using the suction cup method, we found a significant increase of AEL. The IOP reduction following the removal of the suction cup resulted in a significant decrease in AEL and a deepening of ACD compared to baseline values. These biometric changes correlated well with the IOP reductions.

Several studies have shown a decrease of axial eye length with lowered intraocular pressure, as seen after trabeculectomy^{16–18} or after pharmacological treatment.¹⁹ A previous study (Kiss B *et al.* IOVS 1999; ARVO Abstract 2379) showed an AEL shortening of 46 μm (range: 15–70 μm) with a pharmacologically induced reduction of IOP of 5.7 mmHg (range: 3.2–8.3 mmHg). Therefore, the resulting AEL decrease per mmHg IOP decrease was 6.5 $\mu\text{m}/\text{mmHg}$. In the present study, axial eye length change after oculopression was less pronounced with 2 $\mu\text{m}/\text{mmHg}$ (range: 0–4 $\mu\text{m}/\text{mmHg}$). One explanation for this discrepancy could be a direct pharmacological effect of timolol 0.5%, used in the former study, on choroidal blood flow and volume. As the AEL is measured up to the pigment epithelium, it is not possible to discriminate between choroidal thickness and scleral changes by this method. Furthermore, the laser interferometer used in the study by Kiss *et al* had a better resolution than the IOL Master used in the present study.

Although congenitally glaucomatous eyes show an increased axial eye length,²⁰ until now only animal studies have shown that increases in IOP cause axial eye elongation, also referred to as scleral creep.^{21,22} This pressure-dependent scleral creep also increases with temperature, as shown in enucleated eyes.²³ We have shown IOP-dependent AEL changes in human eyes *in vivo* for the first time.

Pressure elevation with the suction cup occurs via suction of the sclera to the cup.²⁴ As the IOP increases, the sclera is stretched resulting in an expansion of the eyeball. This expansion with IOP change is dependent on the eye's scleral rigidity and elasticity. After termination of IOP elevation, as a result of oculopression, the IOP decreases compared to baseline values. This IOP reduction resulted in a concomitant shortening of AEL. This shortening could be a result of a decrease in scleral length owing to the reduced IOP or an increase in choroidal blood flow compensating the reduced ocular fundus pulsations during the increased IOP phase.²⁵

It was interesting that an increase in ACD, therefore a posterior shift of the lens, was found after oculopression. Increased outflow of aqueous during oculopression should result in reduced aqueous volume and thus in a reduction of ACD. However, simultaneous reduction of AEL and increase of ACD reflects a reduction in vitreous volume. Using Silvers' formula of the pressure–volume

relation based on previous measurements of ocular rigidity made on living human eyes,²⁶ the calculated volume reduction as a result of the reduced AEL (6 μl) and the effect of backward movement of the posterior lens pole and, therefore, anterior vitreous surface (10 μl) should lead to a total loss of vitreous volume of 16 μl on average. According to Quigley, *et al*²⁷ an increase of pressure behind the vitreous (e.g. choroidal swelling or scleral compression) increases the absolute pressure difference within the eye — higher in the posterior segment than in the anterior segment. As a consequence, fluid passes from the vitreous and into the posterior chamber of the anterior segment where it exits through the trabecular meshwork and uveoscleral outflow paths. Therefore, a concomitant deepening of the ACD should be seen as shown in our study.

In this study, we were able to show biometric changes of the human eye *in vivo* as a response to IOP changes of short duration. Although a deformation of the entire sclera with the suction cup cannot be fully excluded, the decrease of AEL seen with the decrease of IOP following oculopression gives evidence to a direct interaction of IOP and expansion/contraction of the eye. Scleral rigidity and elasticity of the human eye, as a limiting factor to expansion and contraction forces, obviously play an important role in AEL–IOP relationship. The posterior shift of the lens seen after oculopression indicates a dehydration of the vitreous with scleral compression as a consequence of a pressure gradient within the eye between the posterior and anterior segments. With our experimental set-up, it should be possible to assess scleral rigidity in the human eye *in vivo*. Such measurements may be relevant to further examine the pathogenesis of a variety of ocular diseases, including glaucoma or myopia.

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