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BASIC SCIENCE

The scleral rigidity of eyes with different refractions

Nikolai M. Sergienko · Irina Shargorogska

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Abstract
Background The weakened biomechanical properties of the sclera is an important feature of myopic eyes. The quantitative evaluation in vivo of posterior scleral resistance to the elongation remains a challenge.
Methods This study comprised 172 eyes from 86 subjects with a mean age of 20.6 years (range, 18–28 years). Ultrasound biometry was performed using an immersion technique and the A-scan device (the Biometer AL-1000 - TOMEY). The axial length of the eye was measured twice: before and during the application of an external pressure of 30 g on the eye. The difference between two mean values of AL measurements before and during the pressure application was considered as a degree of change in the axial length that resulted from the IOP elevation.

The data were entered into an Excel spreadsheet (Microsoft Corp.) for subsequent analysis. Statistical analysis was performed using SigmaPlot software (version 11.0, Systat Software, Inc.). A value of 0.05 or less was considered statistically significant.
Results The means ± SD of axial changes before and during the external pressure for hyperopia, emmetropia, myopia 0.5–3.0 D, myopia 3.25–6.0 D, myopia 6.25–12.0 D and myopia over 12.0 D were as follows: 0.03±0.01 mm, 0.05±0.01 mm, 0.18±0.07 mm, 0.31±0.02 mm, 0.38 ± 0.07 mm, and 0.51±0.9 mm, respectively. The difference among groups was statistically significant.
Conclusions In conclusion, our study indicates that the biomechanical properties of the scleral coat, in terms of stretching and AL elongation, are measurable. The hypermetropic and emmetropic eyes possessed stiff sclera. The extent of AL remained practically unchanged during IOP elevation in these eyes. The absolute majority of the myopic eyes revealed a biomechanical weakness of the scleral shell. A higher degree of myopia was associated with increased AL elongation. Our approach to measuring the biomechanical properties of the sclera may have clinical significance in the future.

Keywords Scleral rigidity · Myopia · Intraocular pressure

Introduction

The weakened biomechanical properties of the sclera are a well-known feature of myopic eyes. The hypotheses related to the etiology of myopia include genetic inheritance, influence of intraocular pressure, accommodation and convergence, and environment and lifestyle factors [1–6].

Eye elongation is an important (though not the only) factor contributing to the development of myopia. Variations in the optical parameters of human eyes have been meticulously explored by E.J. Tron [7]. Such variation may result in excessive power of the entire optical system as related to the axial length (AL) in the given eye, even in the case of a completely normal sclera. As a result, a mismatch of the refracting power and axial distance to the retinal plane creates a condition that is conducive to refractive or simple myopia.

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N. M. Sergienko · I. Shargorogska
Department of Ophthalmology,
National Medical Academy of Postgraduate Education,
Kiev, Ukraine

N. M. Sergienko (✉)
Eye Microsurgery Center,
Komarov Ave, 3,
Kiev 03680, Ukraine
e-mail: nmsmicro@gmail.com

However, the majority of myopic eyes exhibit weakened scleras. W.H. Spenser [8] expressed his point of view: "Progressive myopia invariably is associated with enlargement of the posterior segment of the eye and its axial elongation". Histological changes of the sclera in myopic eyes are described in detail [8, 9].

Scleral rigidity has been the subject of a series of investigations, although the majority of them were associated with the precision of intraocular pressure measurements [10–12]. We are unaware of any study investigating the resistance of the posterior sclera in terms of an evaluation of AL elongation in vivo.

We have developed a device and methodology to measure extension of the sclera under an artificially elevated intraocular pressure. The goal of this study was to assess the rigidity in eyes with different refractions.

Materials and methods

This prospective study comprised 172 eyes from 86 subjects. The age of the subjects ranged from 18 to 28 years with a mean age of 20.6 years. Exclusionary criteria were: history of ocular hypertension or glaucoma, ocular surface pathology, history of intraocular surgery or refractive surgery, an inability to comply with the follow-up program, or an unwillingness to participate in this study.

The study was performed at the Department of Ophthalmology, National Medical Academy of Postgraduate Education (NMAPO), Kiev. The participants, mostly students, were recruited on a purely volunteer basis, and their consent was obtained. This study was approved by the ethical committee of the NMAPO.

Refractometry was performed with a Humphrey 597 autorefractometer. Ultrasound biometry was performed using an immersion technique on the A-scan device (the Biometer AL-1000 -TOMEY). The axial length of the eye was measured twice: before and during the application of external pressure on the eye. The intraocular pressure (IOP) was measured by pneumotonometry (Xpert MCT Plus, Reichert).

Examination was carried out with the patients in the supine position (lying down with the face up). The first measurement was conducted after one drop of Alcain (Proxymetacainum, Alcon) was instilled in the eye. After 1 min, one drop of Corneregel (Dexpanthenolum, Bausch&Lomb) was placed on the cornea, and then the ultrasound probe was placed lightly on the cornea. With contact, the AL was measured three times; the mean of the measurements was calculated.

Topical anesthesia was repeated before the second measurement. In order to achieve the IOP elevation artificially, we used a device that utilizes metal tubing weighing 30 g with an inner aperture that is 13 mm in diameter. The device was positioned on the eye, which was examined in such a way that the cornea appeared to be in the center of the aperture of the device (Fig. 1). The device itself retained the eyelids open and moved between them freely. The subject was instructed to keep the opposite eye open and to fixate on a target on the ceiling.

The tip of the probe was introduced into the aperture of the device until contact with the cornea was achieved. Three measurements were taken, and the mean of the measurements was registered.

The repeatability of the AL measurements was evaluated in hypermetropia, emmetropia, and low-myopia groups. If the standard deviation (SD) of the three measurements was 0.15 or less, then the readiness was adopted. For eyes of moderate and high myopia, an SD of 0.2 or less was regarded as acceptable.

The difference between two mean values of AL measurements before and during pressure was considered as the degree of change in axial length as a result of the IOP elevation.

The gained data were entered into an Excel spreadsheet (Microsoft Office Excel 2010; SPSS, Statistical Software for Statistical Analysis). The results were expressed as the mean ± SD. A p value less than 0.05 was considered statistically significant.

Results

Despite the apparent difficulty with direct visualization of the probe tip being introduced inside the device, the variability among the three AL measurements rarely exceeded an acceptable degree.

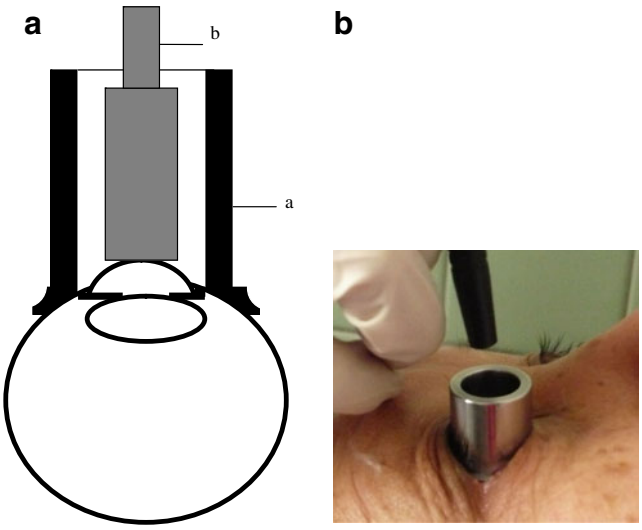

Fig. 1 **a** Schematic representation of the method of axial length measurement: *a* metal tubing of 30 g in weight; *b* ultrasound probe. **b** Position of the ultrasound probe and the loading tubing before the measurement

Technically, the measurement procedures proceeded smoothly. None of the examined subjects experienced any inconvenience. The examinations were conducted on both eyes of all subjects.

Table 1 shows the A-scan biometry results, which are presented as mean ± SD. There was a statistically significant difference in the mean AL values of all neighboring groups ($p<0.05$). Figure 2 demonstrates the comparative results of AL elongation in eyes with different refractions.

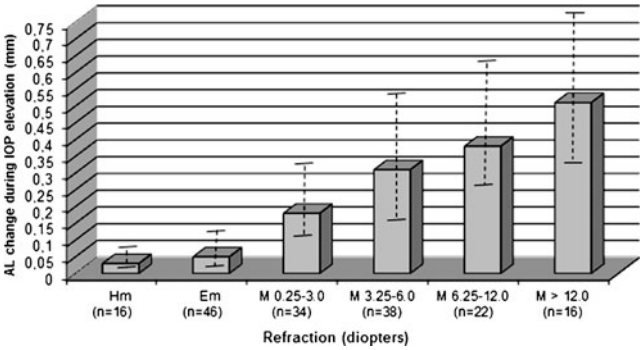

Fig. 2 Axial length elongation as response on IOP loading

Discussion

Deviation of the IOP level is a natural feature in physiological function of the human eye. In the case of hypertension or glaucoma, the IOP parameters can be very high. Therefore, elevating the IOP by applying external pressure for a short time may be considered an imitation of the natural situation.

The application of external pressure in order to reach IOP elevation is well documented; for instance, the ophthalmodynamometry technique involves pressure directed at a single small location behind the limbus. In our study, we localized the pressure to a circular zone approximately 2 mm behind the limbus and in close proximity to the ciliary body. We used a loading of 30 g, although the extent of IOP elevation was not equal for all of the eyes examined. The mechanisms responsible for IOP elevation depend on a series of factors, including the thickness and rigidity of the sclera, volume of the intraocular cavity, and rigidity of the irido-ciliaris diaphragm, which each demonstrate inter-individual variability. It would have been ideal to calibrate the degree of loading in millimeters of mercury for the IOP elevation, but we were unable to do so in this pilot study. However, the information that was gained using the current technique presented beneficial information.

The AL elongation was accompanied by a myopic shift of refraction. However, we did not express elongation in terms of diopters because this would have involved the influence of additional factors. For an eye with an AL of 24 mm, an elongation of 0.38 mm would provide a myopic shift of 1.0 D. For an eye with myopia of 15.0 D and an AL of approximately 30 mm, such an elongation would result in an increase in the myopic shift of only 0.5 D. In our opinion, the measurement of AL elongation in millimeters is more relevant and straightforward.

Our findings demonstrated that the scleral shell of emmetropic and especially hypermetropic eyes appeared to be stiff and therefore successfully withstood the IOP increase. The mean values reflecting the IOL elongation in response to the loading were negligible: 0.03 mm and 0.05 mm for the hypermetropia and emmetropia groups, respectively; however, a statistically significant difference between these two groups (<0.05) was noted.

Examination of the myopic eyes revealed changes in the biomechanical properties of the sclera. The mean values of AL elongation increased steeply in eyes from low to high myopia (Fig. 2): from 0.18 mm to 0.51 mm, respectively. In some myopic eyes of > −6.0 D, the sclera appeared to be especially weak. The difference between groups of myopic eyes was statistically significant. In the low-myopia group, six out of 36 eyes (16.7%) displayed scleral stiffness. The AL elongation measured ranged from 0.06 mm to 0.07 mm, which is characteristic of emmetropia. These eyes likely exhibited simple (refractive) myopia.

The histological images obtained may provide an explanation for this excessive weakness of the sclera [8, 9]. During the initial stages of the progression of myopia, the

Table 1 Comparison of the axial length elongation during IOP elevation in eyes with different refraction

Refractions, D	AL initial (mean ± SD)	AL during pressure (mean ± SD)	AL change during IOP elevation (mm) (mean ± SD)	Range of deviation (mm)	IOP (mmHg) (mean ± SD)	Number of eyes
Hypermetropia	22.13±0.02	22.16±0.01	0.03±0.01 *	0.01–0.04	14.17±1.3 *	16
Emmetropia	23.36±0.01	23.41±0.01	0.05±0.01 *	0.01–0.07	12.52±1.01 *	46
Myopia 0.25–3.0 D	24.17±0.07	24.35±0.07	0.18±0.07 *	0.06–0.27	15.14±1.1 *	34
Myopia 3.25–6.0 D	25.04±0.1	25.35±0.1	0.31±0.02 *	0.10–0.48	16.33±1.3 *	38
Myopia 6.25–12.0 D	26.13±0.07	26.51±0.07	0.38±0.07 *	0.21–0.59	17.47±1.2 *	22
Myopia >12.0 D	29.48±0.09	29.99±0.09	0.51±0.09 *	0.28–0.73	18.12±1.3 *	16

* $p<0.05$

arrangement of the scleral fibers is normal. In eyes in the advanced stages of progressive myopia, marked abnormality is present. The collagen fiber bundles that compose the basic scleral structure are thinned and atrophic. The fibers are narrowed and widely separated from one another. In most cases, scleral ectasia appears at the posterior segment of the eyeball; this condition is denoted as posterior staphyloma. Sometimes the thinned sclera is less than 100 μm in thickness. Pathological scleral structure is likely a consequence of aberrant collagen fibrogenesis, which results in abnormal collagen metabolism [8]. Equatorial regions of the myopic eyes are also thinned and may show ectasias. Both the posterior pole and the entire weakened scleral coat contribute to excessive stretching and elongation of the eyes. Degenerative myopia is typically associated with stretching of the fluid-pressurized globe.

Our approach of measuring ocular rigidity may be of clinical significance. Myopia can be divided into two broad categories: refractive (simple) and progressive. A detection of stiff sclera in eyes of low or moderate myopia suggests that these eyes have refractive myopia, which progresses only minimally. Weakened scleral rigidity, even in eyes with low myopia, especially at a young age, may serve as a warning signal for the pending myopia progression.

The myopic eyes over −6.0 D were characterized by variability in scleral rigidity. The eyes having an excessively weak sclera are an indication for surgical-scleral reinforcement, in which a donor sclera strip is sutured at the sclera ectasia. The reinforcement of the pathologically thin sclera can slow or arrest the progression of myopia.

Though the precision of our AL measurements obtained using the immersion ultrasound A-scan technique was sufficient to discriminate an evident difference in the scleral ability to resist IOP elevation, partial-coherence interferometry may provide more persuasive results in the future.

In conclusion, our study indicates that the biomechanical properties of the scleral coat (in terms of stretching and AL elongation) are measurable. The hypermetropic and emmetropic eyes possess stiff sclera. Their AL remained practically unchanged during the elevation in IOP induced by the application of 30 g of external pressure. The absolute majority of myopic eyes revealed biomechanical weakness of the scleral shell. A higher degree of myopia was associated with increased AL elongation. Our approach to measuring the biomechanical properties of the sclera may have clinical significance in the future.

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