Corneal hysteresis values in normal Egyptian population

Alaa A. Ali

Department of Ophthalmology, Memorial Institute of Ophthalmology, Giza, Egypt

Correspondence to Alaa A. Ali, MD, 13 Mohamed Ezz El-Arab Street, Cairo 11647, Egypt
Tel: +0 020 227 958 478;
e-mail: ali1ibrahim@yahoo.com

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Introduction
Knowledge of the cornea's biomechanical properties is important for a wide variety of applications within ophthalmology. Corneal biomechanical variations are known to affect the accuracy of intraocular pressure measurements and may be used to identify early corneal disease and may assist in predicting refractive outcomes following corneal refractive surgery. It has also been suggested that corneal biomechanical properties may reflect globe biomechanics, and thus give an indication of the susceptibility of developing glaucomatous damage.

Aim of the work
The purpose of this study was to explore the relationships between Ocular Response Analyzer-generated corneal biomechanical characteristics and age in a sample of Egyptian population.

Materials and methods
Corneal hysteresis (CH) and corneal resistance factor (CRF) were measured in 195 Egyptians of different age groups.

Results
The mean CH value was 10.25 ± 0.12 mmHg (range, 6.5–14.4), and the mean CRF was 10.25 ± 0.15 mmHg (range, 4.9–14.2). The CH value was lower in older eyes, and the difference between the youngest age group (19–40 years) and the oldest age group (40–71 years) was statistically significant (*t*-test = 0.01). The mean CH in the youngest age group was 11.1 ± 0.14, and that in the oldest age group was 9.8 ± 0.21. The mean CRF in the youngest age group was 10.9 ± 0.18, and that in the oldest age group was 10.1 ± 0.19.

Conclusion
This study of corneal biomechanics in normal Egyptian eyes describes the interactions between age and Ocular Response Analyzer metrics. The study reveals that age is significantly associated with CH and CRF. This may help in diagnosis and treatment.

Keywords:
corneal hysteresis, Egyptian, normal

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Introduction

Ocular biomechanics is an increasingly important field. Overt corneal biomechanical problems have long been seen in keratoconus and corneal ectasia after corneal refractive surgery. In keratoconus, there are clear changes in the corneal collagen, and the cornea loses rigidity over time and becomes ectatic; in corneal ectasia, the ablation of some corneal stroma can weaken the cornea and result in progressive corneal deformation [1]. In refractive surgical practice, patients with pre-existing ectasia usually are excluded from treatment. However, individual variations in biomechanical integrity and postoperative wound healing preclude preoperative identification of all potentially vulnerable patients. There is considerable but mostly indirect evidence suggesting that the biomechanical corneal properties vary with age [2]. Quantifying the biomechanical corneal properties is difficult, but the available evidence supports corneal stiffening with age; in other words, there is an increment in Young's modulus [3], the ocular rigidity coefficient, that expresses the elastic properties of the globe [4], the cohesive tensile strength, and the breaking force of a tissue [5]. Young's modulus, also known as the tensile modulus, is a measure of the stiffness of an elastic material and is a parameter used to characterize elastic materials. Perhaps the single best descriptor of a given material's biomechanical properties at low strain is its Young's modulus (E), which is defined as the ratio of stress to strain, or where stress is an applied force (load/unit area), and strain is the deformation of the material to which stress has been applied (displacement/unit length): Young's modulus (E) = stress/strain. This parameter depends on the material's physical properties and dimensions. Importantly, when stress is applied and removed, elastic materials follow the same path during deformation and relaxation and ultimately recover the original shape. Viscoelastic materials, such as the cornea, can also recover the original shape after stress is removed, but the relaxation path differs from the deformation path;

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therefore, the relationship between stress and strain is nonlinear, and stiffening occurs as strain increases [6,7] (Fig. 1). This behavior, referred to as corneal hysteresis (CH), results from dissipation of energy as heat in the material.

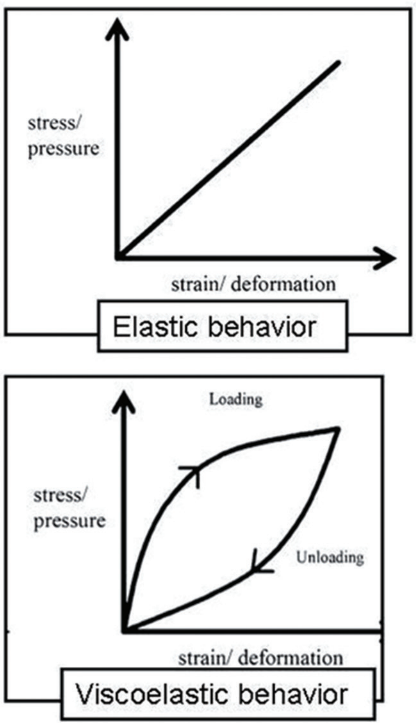
In fact, the effect of the corneal thickness on Goldmann applanation tonometer measurements may be less important compared with the effect of variations in corneal elasticity [4]. CH is a measure of the viscoelastic properties of the corneal tissue together with the corneal resistance factor (CRF) – that is, the 'energy absorption capability' of the cornea – and indicates the biomechanical integrity [8].

Knowledge of the cornea's biomechanical properties is important for a wide variety of applications within ophthalmology. Corneal biomechanical variations are known to affect the accuracy of intraocular pressure (IOP) measurements [9,10] and may be used to identify early corneal disease [11,12] and may assist in predicting refractive outcomes following corneal refractive surgery [13]. It has also been suggested that corneal biomechanical properties may reflect globe biomechanics, and thus give an indication of the susceptibility of developing glaucomatous damage [5].

Until recently, most investigations evaluating corneal biomechanics were based on ex-vivo tissue. However, the Reichert Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, New York, USA) has facilitated an in-vivo measurement of aspects of corneal biomechanical properties. The device measures the central corneal response to indentation using a rapid jet of air and provides two metrics of corneal biomechanics, CH and the CRF. It is thought that CH predominantly reflects the viscous dampening properties of the cornea, whereas CRF, a metric empirically derived to be strongly correlated with central corneal thickness, is thought to be most associated with the cornea's elastic response [14]. However, how these metrics relate to conventional biomechanical measurements is still relatively unclear. Studies examining the ORA biomechanical metrics have suggested associations with age, central corneal thickness, and IOP [15,16]; however, some suggest no association with these parameters.

The purpose of this study was to evaluate the relationships between ORA-generated corneal biomechanical characteristics and age in normal Egyptian eyes.

Figure 1



The relationship between stress and strain is linear in an elastic behavior and nonlinear in a viscoelastic behavior.

Aim of the work

The purpose of this study was to explore the relationships between ORA-generated corneal biomechanical characteristics and age in a sample of Egyptian population.

Materials and methods

Inclusion/exclusion criteria

Study participants comprised normal people attending the Memorial Institute of Ophthalmic Research for check-up. Data were collected between 2008 and 2012. Participants underwent a complete ophthalmic check-up to exclude any pathology. Participants were excluded from the study if they had any signs of corneal pathology, corneal astigmatism of 3 diopters or greater or a history of incisional or intraocular surgery, suspicious optic disc appearance, IOP of 20 mmHg or greater, a history of diabetes, or a family history of glaucoma in a first-degree relative. Soft-contact lens wearers were required to remove their lenses at least 24 h before study participation; rigid contact lens wearers were excluded from the study. For eligible participants, only one randomly chosen eye was measured for the study.

Procedure and data collection

Before instillation of topical anesthesia, participants underwent ORA measurements. Subsequently, three good quality waveform scans, defined as having symmetry in height between the two peaks of the waveform, were recorded, and the mean value was used in subsequent analysis. Following instillation of topical corneal anesthesia (Benox 0.5% with fluorescein dye), IOP measurements were made using the Goldmann applanation tonometer. Three Goldmann applanation tonometer measurement were taken; a minimum 2-min interval was left between IOP measurements to minimize the tonographic effects of repeated tonometry measurements [9]. The mean IOP reading was calculated for each participant and was used in the analyses.

Data analysis

On the basis of previous pilot data from an unrelated data set, it was calculated statistically that a sample of 194 eyes was required to achieve a correlation between CH and age with 80% power at the *t*-test and at *P* value less than 0.05 level. In this study, the response variable of interest was either CH or CRF and the predictor variable of interest was only one variable – namely, age. On this basis, 195 participants were randomly selected from the sample of the Egyptian population attending the institute from all governorates, as the institute is a referral hospital.

Ethical considerations

All ethical considerations were respected, including subject information and approval of this noninvasive procedure.

Results

Data were collected from 195 participants and the demographic data are presented in Table 1. All participants were Egyptians. Their ages ranged from 19 to 71 years, with an average age of 45 years. There were 44 male and 54 female patients. A total of 98 right eyes and 97 left eyes were tested (Graph 1).

A high correlation and a low difference between the right and the left eye of the same patient show the accuracy of measurements (*t*-test, $P < 0.001$).

The mean CH value was 10.25 ± 0.12 mmHg (range, 6.5–14.4), and the mean CRF was 10.25 ± 0.15 mmHg (range, 4.9–14.2) (Graph 2 and Table 2).

The CH value was lower in older eyes, and the difference between the youngest age group (19–40 years) and the oldest age group (40–71 years) was statistically significant (*t*-test, $P = 0.01$).

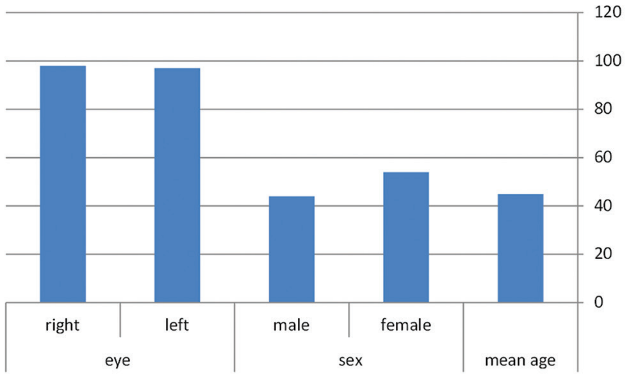
The mean CH in the youngest age group was 11.1 ± 0.14, and that in the oldest age group was 9.8 ± 0.21 (Graph 3 and Table 3). The mean CRF in the youngest age group was 10.9 ± 0.18, and that in the oldest age group was 10.1 ± 0.19 (Graph 3).

No significant correlation was found between age and IOP (corneal corrected) (*t*-test, $P = 0.82$), or age and IOP (goldman) (*t*-test, $P = 0.11$).

Discussion

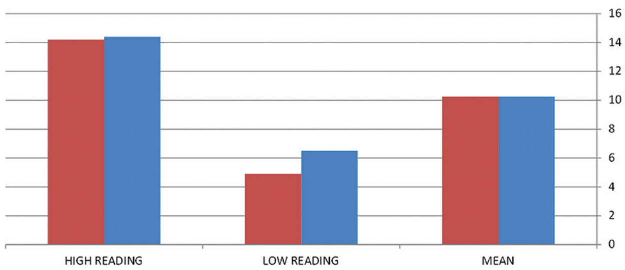
It has been suggested that CH represents the viscoelastic capacity of the cornea – that is, the cornea's

Graph 1



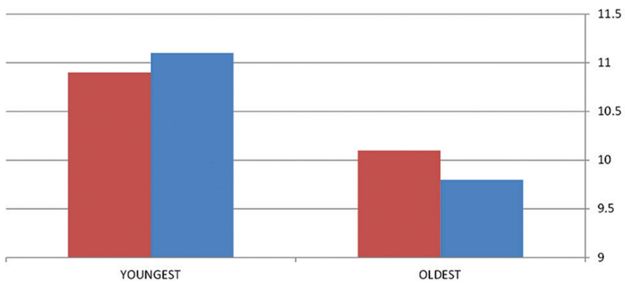
Demographic patient data.

Graph 2



Values of corneal hysteresis (blue) and corneal resistance factor (red) in normal Egyptians.

Graph 3



Values of corneal hysteresis and corneal resistance factor in the youngest age group (blue) and the oldest age group (red) of normal Egyptians.

Table 1: Demographic patient data

Eye		Sex		Mean age
Right	Left	Male	Female	
98	97	44	54	45

Table 2: Values of CH and CRF in normal egyptien

Item	High reading	Low reading	Mean
Corneal Hysteresis	14.4	6.5	10.25
Corneal Resistance Factor	14.2	4.9	10.25

Table 3: Values of CH and CRF in youngest age group and oldest age group of normal egyptien

Item	Youngest	Oldest
Mean Corneal Hysteresis	11.10	9.80
Mean Corneal Resistance Factor	10.90	10.10

ability to dampen and dissipate applied energy. Hysteresis is dependent on the relative contributions of both elasticity and viscosity, and it has been shown that alterations in either component will have very different and sometimes opposing effects on measured hysteresis [4]. Our finding that CH reduces with age corroborates the findings of experimental ex-vivo studies that show an increase in collagen cross-linking with age [17], which results in a reduction in the viscosity of the cornea and thus an increase in the 'stiffness' of the structure [16]. The data are also in agreement with previous clinical work evaluating the effect of age on ORA-measured corneal biomechanical properties [18]. Taken together, these findings suggest that aging results in an overall reduction in the dampening capacity of the cornea.

CRF was intended to quantify the overall corneal viscoelastic resistance to indentation. The fact that CRF reduces with age is counterintuitive, as it might be expected that the increase in corneal 'stiffness' resulting from an age-related increase in corneal collagen cross-linking would result in an increased resistance to deformation; however, our results do agree with previous findings [19]. The CRF represents a metric of corneal resistance to a near instantaneous indentation force applied axially. Our data suggest that the assumption that CRF reflects overall corneal rigidity may be an oversimplification and that other factors need to be considered when interpreting its value.

One may postulate that CRF represents overall corneal rigidity, as a reduced corneal rigidity would be associated with a reduced scleral rigidity, and so CRF may give an idea about scleral rigidity. However, further work is required to establish the significance of the relationship and how corneal biomechanics relate, if at all, to scleral biomechanics.

Conclusion

In conclusion, this study on corneal biomechanics in normal Egyptian eyes describes the interactions between age and ORA metrics and finds that age is significantly associated with CH and CRF. The mean CH value was 10.25 mmHg (range, 6.5–14.4), and the mean CRF was 10.25 mmHg (range, 4.9–14.2). The mean CH decreases with age, and the mean CRF also decreases with age. However, the variation in both these ORA metrics implies that not only age but there are also other elements contributing to CH and CRF measurement.

Finally, condensing corneal biomechanical measures to a single summary metric will never completely describe the cornea's properties. Recently, investigators evaluating the ORA applanation signal have found that variations in specific signal elements are better descriptors of the corneal response to indentation, particularly following refractive surgery procedures [20]. Further work is required to establish the validity of these new parameters and how they relate to more conventional biomechanical measures.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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