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Variability in biomechanical properties of the fibrous tunic of the eye in a healthy population

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Studying biomechanical properties of the fibrous tunic of the eye meets current clinical demands. Previous studies have proved bidirectional corneal applanation suitable for this purpose. The so called corneal elasticity coefficient is more informative in terms of corneal elastance than the two other parameters measured during bidirectional corneal applanation, namely, corneal resistance factor and corneal hysteresis. All three are known to have wide normal ranges. The **aim** of the present study was to determine the range of corneal resistance factor, corneal hysteresis, and corneal elasticity coefficient in a normal population. **Material and methods**. This work summarizes data from 2205 patients (4410 eyes) with no ophthalmic pathology who got their ocular biomechanics examined with an Ocular Response Analyzer. **Results**. Normal ranges of biomechanical parameters of the fibrous tunic have been determined. Considerable variation has been demonstrated in central corneal thickness (from 448 to 685 μm, with the mean of 563±37 μm). Moreover, the corneal resistance factor, corneal hysteresis, and corneal elasticity coefficient have been shown to have almost equal means and to decrease with age.

***Keywords**: biomechanics, cornea, sclera, fibrous tunic, bidirectional corneal applanation, intraocular pressure, refractive surgery.*

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The study is important due to a variety of clinical requirements related to new biomechanics examination methods, the need for diagnostics and monitoring of ectatic diseases of the cornea, adequate choice of keratorefractive surgery parameters, proper interpretation of intraocular pressure (IOP) values and, consequently, adequate evaluation of IOP level and monitoring of the glaucoma process [1-4].

Intravital study of biomechanical properties of the cornea is usually based on the evaluation of its shape changes in response to a mechanical stimulus that can be done by applanating the cornea with an air impulse (non-contact tonometry with bidirectional dynamic applanation of the cornea) or using Maklakov tonometers of various weight (elastotonometry), as well as by impressing the cornea using the Schiotz tonometer (calculation of Friedenwald's rigidity coefficient) [5-8].

Of all the methods described, Ocular Response Analyzer (ORA) is the most widely used in clinical practice. Its operation is based on bidirectional applanation of the cornea with an air impulse. The conducted research has confirmed application of bidirectional applanation of the cornea for measuring its biomechanical properties: with increase of corneal thickness these values also increased, under keratoconus they decreased, and after penetrating keratoplasty – increased again [9, 10]. Excimer laser ablation resulted in weakening of corneal mechanical properties [11, 12].

Since corneal hysteresis reflects visco-elastic properties, which is manifested in partial absorption of the air impulse energy, its correlation with corneal thickness is lower. Corneal resistance factor as an estimate indicator correlates to a higher degree with central corneal thickness and its changes reflect elastic properties of the cornea. Hence, when studying biomechanical properties of the cornea in keratoconus patients, as well as in post keratorefractive surgery cases with corneal ablation, it's more informative to analyze corneal resistance factor rather than corneal hysteresis [13, 14].

However, in some clinical settings standard Ocular Response Analyzer measurements reflect not quite adequately expected changes of corneal mechanical strength, such as marked reduction of corneal hysteresis with the increasing IOP. In this regard, a new approach to studying biomechanical properties of the cornea using ORA data has been developed. The method is based on deceleration dynamics of central corneal area at the moment of maximum impression (so called dynamic pneumo-impression). As a result, a coefficient of elasticity has been calculated [15].

The corneal elasticity coefficient characterizes elastic properties of the cornea in a better way than corneal resistance factor or corneal hysteresis. Compared with known methods, dynamic pneumo-impression approach allows measurements of biomechanical properties of the cornea to be less dependent on IOP.

Standard biomechanical properties values measured by bidirectional pneumoapplanation of the cornea have a wide normal range.

The aim of the study was to define ranges of corneal resistance factor, corneal hysteresis and corneal elasticity coefficient in normal population.

Material and methods

This work summarizes the examination results of 2205 patients (4410 eyes) with no ophthalmological abnormalities (excluding age-related cataract) who hadn't previously undergone any ophthalmosurgeries. The group consisted of 540 (24.5%) male and 1665 (75.5%) female patients of 59.7±14.4 mean age. The age distribution is shown in **Table 1**.

Table 1. **Distribution of patients by age (according to WHO recommendations)**

Age interval	Number of patients (% of all patients)
18—44	319 (14,5)
45—59	620 (28,1)
60—74	974 (44,2)
75—90	292 (13,2)

The Ocular Response Analyzer (ORA, Reichert, USA) measures viscoelastic properties of the fibrous tunic of the eye and IOP with bidirectional applanation of the cornea with a rapid air pulse (about 20 ms). The designers of ORA device suggested evaluating biomechanical response of the cornea on the basis of pressure difference at the moment of inward and outward applanation events, and calculation of the two parameters that characterize biomechanical properties of the cornea: corneal hysteresis (CH) and corneal resistance factor (CRF). The corneal resistance factor is herewith an estimate indicator with high correlation to central corneal thickness while its alteration reflects elastic properties of the cornea. The corneal hysteresis characterizes viscoelastic properties of the cornea conditioning partial energy absorption of the air impulse.

Calculation of the corneal elasticity coefficient (Ke) is done by an original patented method (RF patent № 2361504 registered 07.12.2007) by analyzing cornea deceleration dynamics at the moment of indentation. We have suggested the following formula for analyzing various parameters of applanation:

$$Ke = k_p \times \frac{\sum_{t_{(minx''(t))}}^{t_{max}} \left(x''(t) \times \ln(t - t_{(min(x''(t)))})\right)}{\sum_{t_{(minx''(t))}}^{t_{max}} x''(t)},$$

where k_p – conversion factor, t – time after indentation onset, x(t) – indentation depth of central corneal area.

Results

The examination of central corneal thickness has showen significant variability of the biometric parameter, ranging from 448 to 685 mkm for all patients. The mean value was 563±37 mkm. Gender differences of the parameter proved to be insignificant: mean value was 568±39 mkm for the male patients and 562±36 mkm for the female. There was also no significant dependency of CCT on age discovered, however the parameter indicated overall decrease in the age groups, as seen in **Table 2.**

Table 2. **Central corneal thickness in different age groups**

Age range	Central corneal thickness (M±y), mkm
18—44	584±40
45—59	571±37
60—74	562±36
75—90	550±33

Intraocular pressure analysis was performed for the purpose of standardization of the biomechanical properties. As IOP may influence viscoelastic properties of the fibrous tunic of the eye, biomechanical properties in different groups of patients can only be properly compared when the tonometric parameters are equal. In our study, no reliable changes in corneal compensated pressure were observed with age. However, Goldmann-corellated IOP results was seen to decrease (**Table 3).**

Table 3. **Tonometry indices (M±σ) in different age groups**

Age interval	IOPcc, mm Hg	IOPg, mm Hg
18—44	17,3±3,3	19,2±4,3
45—59	17,2±2,8	18,2±3,6
60—74	17,0±2,8	17,4±3,5
75—90	16,5±2,7	16,2±3,3

The analysis of distribution of corneal resistance factor and corneal hysteresis showed that those parameters have nearly equal range of values, however, the first one is more variable (**Fig. 1**).

Age-related changes in biomechanical properties determined by bidirectional pneumoapplanation of the cornea were manifested in the decrease of CRF and CH. However, the correlation between those parameters and the age did not change and remained close to one. Moreover, the corneal elasticity coefficient decreased for each age range (**Table 4**).

As can be seen from the above, the younger age group showed the highest mean values of biomechanical properties with maximum standard deviation. Normal distribution typical of the most biological parameters has been in all age groups. The decrease of mean values and standard deviation with age is statistically reliable and characterizes the tendency of fibrous tunic "biomechanics" to change in nominally healthy eyes. The retention of CH to CRF ratio seems to occur due to the specificity of these parameters calculation and can be used to evaluate the condition of the cornea and sclera in pathological processes. However, the difference of standard deviation of CH and CRF allows the ratio to be considered informative only in the midrange of the values.

No marked gender difference in biomechanical properties of eye fibrous tunic has been observed. Corneal resistance factor, corneal hysteresis and corneal elasticity coefficient difference between male and female groups was statistically unreliable. It averaged in 0.3; 0.2 mmHg and 0.1 (absolute values) respectively.

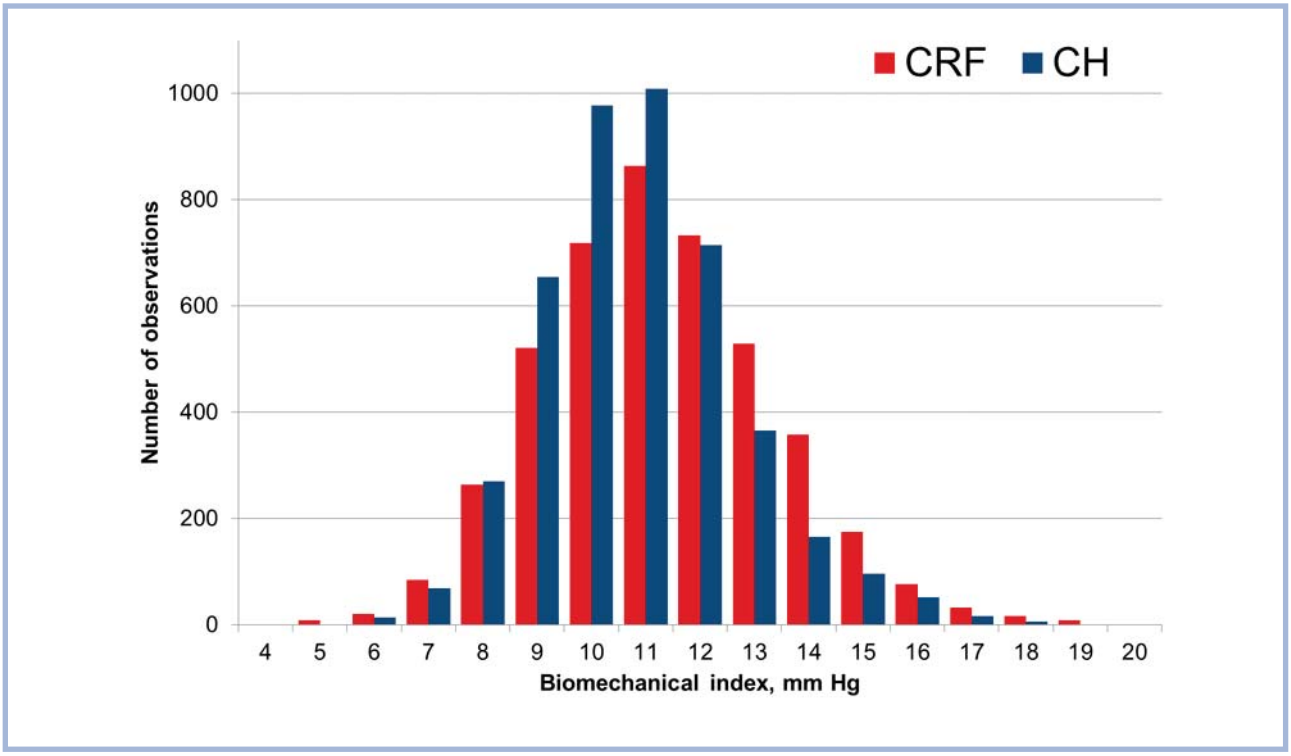

Fig. 1. **Distribution biomechanical properties of the fibrous tunic of the eye in healthy population.**

Table 4. **Values of eye fibrous tunic biomechanical properties (M±σ) in different age groups**

Age range	CRF, mm Hg	CH, mm Hg	Ke
18—44	12,4±2,5	11,7±1,9	12,2±1,3
45—59	11,8±1,9	11,2±1,5	11,7±1,2
60—74	11,1±1,9	10,6±1,4	10,4±1,5
75—90	10,3±1,7	10,1±1,2	9,4±1,1

Table 5. **Ranges of eye fibrous tunic biomechanical properties measured by bidirectional pneumo-applanation**

Interval levels	CRF, mmHg	CH, mmHg	Ke
Very low	Below 7.3	Below 7.8	Below 8,6
Low	7.3—10.3	7.0—10.0	8.6—10.2
Medium	10.4—12.4	10.1—11.7	10.3—11.9
High	12.5—15.5	11.8—14.0	12.0—13.6
Very high	Above 15.5	Above 14.0	Above 13.6

Judging from the obtained results and with respect to age peculiarities, a conventional "norm" scale may be used for interpretation of the research results by means of bidirectional pneumo-applanation of the cornea (as displayed in **Table 5**).

Conclusion

Dynamic pneumo-applanation of the cornea enables studying biomechanical properties of the fibrous tunic of the eye in vivo.

Values of the measurements that characterize biomechanical properties in normal population were distributed normally (Gauss), but with a wide range.

Criteria of an assessment of corneal resistance factor, corneal hysteresis and the elasticity coefficient based on the statistical analysis of big group of patients were been created.

REFERENCES

1. Avetisov S.E., Bubnova I.A., Antonov A.A. Corneal biomechanics: clinical importance, evaluation, possibilities of sistemization of examination approaches. *Vestnik oftalmologii*. 2010;126(6):3-7.
2. Hirneiss C., Neubauer A.S., Yu A., Kampik A., Kernt M. Corneal biomechanics measured with the ocular response analyser in patients with unilateral open-angle glaucoma. *Acta ophthalmologica*. 2011;89(2):e189-92.
   doi: 10.1111/j.1755-3768.2010.02093.x
3. Roberts C. The cornea is not a piece of plastic. *Journal of refractive surgery*. 2000;16(4):407-13.
4. Saad A., Lteif Y., Azan E., Gatinel D. Biomechanical properties of keratoconus suspect eyes. *Investigative ophthalmology & visual science*. 2010;51(6):2912-6.
   doi: 10.1167/iovs.09-4304
5. Avetisov S.E., Bubnova I.A., Antonov A.A. Once more about the diagnostic capacities of elastic tonometry. *Vestnik oftalmologii*. 2008;124(5):19-21.
6. Lau W., Pye D. A clinical description of Ocular Response Analyzer measurements. *Investigative ophthalmology & visual science*. 2011;52(6):2911-6. doi: 10.1167/iovs.10-6763
7. Luce D.A. Determining in vivo biomechanical properties of the cornea with an ocular response analyzer. *Journal of cataract and refractive surgery*. 2005;31(1):156-62.
   doi: 10.1016/j.jcrs.2004.10.044
8. Moses R.A. Theory of the Schiotz tonometer and its empirical calibration. *Transactions of the American Ophthalmological Society*. 1971;69:494-562.
9. Wasielica-Poslednik J., Berisha F., Aliyeva S., Pfeiffer N., Hoffmann E.M. Reproducibility of ocular response analyzer measurements and their correlation with central corneal thickness. Graefe's archive for clinical and experimental ophthalmology = Albrecht von Graefes Archiv fur klinische und experimentelle Ophthalmologie. 2010;248(11):1617-22.
   doi: 10.1007/s00417-010-1471-1
10. Yenerel N.M., Kucumen R.B., Gorgun E. Changes in corneal biomechanics in patients with keratoconus after penetrating keratoplasty. *Cornea*. 2010;29(11):1247-51.
   doi: 10.1097/ICO.0b013e3181ca6383
11. Ryan D.S., Coe C.D., Howard R.S., Edwards J.D., Bower K.S. Corneal biomechanics following epi-LASIK. *Journal of refractive surgery*. 2011;27(6):458-64.

doi: 10.3928/1081597X-20110112-01

12. Shah S., Laiquzzaman M., Yeung I., Pan X., Roberts C. The use of the Ocular Response Analyser to determine corneal hysteresis in eyes before and after excimer laser refractive surgery. Contact lens & anterior eye : the journal of the British Contact Lens Association. 2009;32(3):123-8.

doi: 10.1016/j.clae.2009.02.005

13. Avetisov S.E., Novikov I.A., Bubnova I.A., Antonov A.A., Siplivyi V.I. Investigation of the biomechanical properties of the cornea by bidirectional applanation: new approaches to interpreting the results. *Vestnik oftalmologii*. 2008;124(5):22-4.
14. Kirwan C., O'Malley D., O'Keefe M. Corneal hysteresis and corneal resistance factor in keratoectasia: findings using the Reichert ocular response analyzer. Ophthalmologica Journal international d'ophtalmologie International journal of ophthalmology Zeitschrift fur Augenheilkunde. 2008;222(5):334-7.
   doi: 10.1159/000145333
15. Avetisov S.E., Novikov I.A., Bubnova I.A., Antonov A.A., Siplivyi V.I. Determination of corneal elasticity coefficient using the ORA database. *Journal of refractive surgery*. 2010;26(7):520-4.
   doi: 10.3928/1081597X-20091030-01