Changes in Corneal Biomechanics and Glaucomatous Visual Field Loss

Eric Chan, MD, Kaileen Yeh, MD, Sasan Moghimi, MD, James Proudfoot, MSc, Xiongfei Liu, MD, Linda Zangwill, PhD, and Robert N. Weinreb, MD

Precis: A lower baseline corneal hysteresis and a decrease in corneal resistance factor (CRF) over time are associated with higher risk of visual field progression in glaucomatous and glaucoma suspect eyes.

Purpose: The aim was to investigate the longitudinal change in CRF and cornea hysteresis (CH) as risk factors for visual field progression.

Materials and Methods: In this prospective observational cohort study, 72 eyes of 48 glaucoma or glaucoma suspect patients were followed for an average of 4.5 years. Baseline and follow-up CH and CRF measurements were performed with the Ocular Response Analyzer (Reichert Ophthalmic Instruments Inc., Depew, N.Y.). Evaluation of rates of visual field change during follow-up was performed using visual field mean deviation. Univariable and multivariable linear mixed models assessed the relationship of visual field progression with baseline CRF and CH as well as with changes in CRF and CH.

Results: The mean baseline CH was 9.0 (95% confidence interval: 8.6-9.4) mm Hg and the mean baseline CRF was 9.3 (95% confidence interval: 8.8-9.9) mm Hg. There was no statistically significant difference in average CH and CRF measurements over time. In multivariable modeling adjusting for age, race, and mean intraocular pressure during follow-up, each 1 mm Hg lower in baseline CH and 1 mm Hg decrease in CRF over time were associated with a 0.12 (P = 0.042) and 0.14 dB/year (P = 0.007) faster rate of visual field mean deviation loss, respectively. Similar findings were found in glaucoma eyes but not found in glaucoma suspect eyes.

Conclusion: Visual field progression was associated with a lower baseline CH and a decrease in CRF over time. Assessment of corneal resistance and elasticity at baseline and during follow-up examinations should be considered to identify those eyes at highest risk of visual field progression.

Key Words: glaucoma, corneal hysteresis, progression, visual field (J Glaucoma 2021;30:e246–e251)

The pathophysiology of primary open angle glaucoma (POAG) is still not fully understood. However, several risk factors for progression have been identified, including high intraocular pressure (IOP), disc hemorrhage, African American race, advanced age, and family history of glaucoma. Currently, the mainstay of treatment focuses on reducing IOP. However, despite a low IOP, some patients continue to worsen. The Early Manifest Glaucoma Trial (EMGT) and the Ocular Hypertension Treatment Study (OHTS) identified thin central corneal thickness (CCT) as a risk factor for glaucomatous progression. This may be due, at least in part, to the relationship between IOP and CCT or scleral thickness, and an underestimation of IOP.

Other biomechanical properties of the eye also have been investigated including corneal hysteresis (CH), which measures the viscoelastic property of the cornea when subjected to deformation. The ocular response analyzer (ORA) measures CH by analyzing the difference between the corneal response to initial deformation and reformation when subjected to an air pulse. Multiple studies have demonstrated that a lower baseline CH is associated with an increased risk of developing POAG as well as faster rate of glaucoma progression.

It has been hypothesized that a lower CH indicates a weaker extracellular matrix in the lamina cribrosa or peripapillary sclera, thus rendering the optic nerve more susceptible to damage. The ORA also measures the corneal resistance factor (CRF), a separate biomechanical property, that has been reported to be significantly higher in those with ocular hypertension (OHT) than POAG, indicating a possible protective factor. Several studies have reported on the relationship between one baseline measurement of CH or CRF and visual field progression, but none have described the change in these variables over time.

This study examined the changes of CRF and CH, and their respective association with visual field progression over time in glaucoma and glaucoma suspect eyes.

MATERIALS AND METHODS

This was an observational cohort study of patients with glaucoma or suspected glaucoma. Participants from this study were enrolled in the Diagnostic Innovations in Glaucoma Study (DIGS, clinicaltrials.gov NCT0021897). The DIGS is an ongoing prospective longitudinal study designed to
evaluate optic nerve structure and visual function in glaucoma. Study participants underwent a pre-established protocol for follow-up visits which included clinical examination and other diagnostic imaging and functional tests. The UC San Diego Human Research Protection Program Institutional Review Board approved all methodology and all methods adhered to the tenets of the Declaration of Helsinki for research involving human subjects.

All patients had a baseline comprehensive ophthalmologic examination including IOP measured using Goldmann applanation tonometry (GAT; Haag-Streit, Konig, Switzerland), gonioscopy, dilated funduscopy examination, stereoscopic optic disc photography, standard automated perimetry using the Swedish Interactive Threshold Algorithm 24-2 test, and CCT measurements obtained by a trained technician using ultrasonographic pachymetry (Pachette GDH 500; DGH Technology Inc., Philadelphia, PA). Semiannual examinations included IOP measurement by Goldmann applanation and standard automated perimetry testing. The quality of visual fields was reviewed by the Visual Field Assessment Center (VisFACT) staff according to a standard protocol.

Eligible glaucoma suspects and patients had open angles on gonioscopy and demonstrated glaucomatous optic neuropathy based on stereoscopic optic disc photography and/or OHT (IOP > 21 mm Hg), with or without glaucomatous visual field damage at baseline. A minimum of 5 visual fields performed during the follow-up time was required for inclusion. Participants were excluded if they had history of any intraocular surgery during the follow-up period or prior intraocular surgery (except for uncomplicated cataract surgery). Patients with corneal or retinal pathologies were excluded from the study. Eyes were classified as glaucoma suspects if they had OHT and/or glaucomatous optic neuropathy without repeatable visual field defects. Eyes were classified as glaucomatous if they had glaucomatous optic neuropathy with repeatable visual field defects and further subdivided by baseline mean deviation (MD) as mild for MD ≥ −6 dB, moderate for MD < −6 dB and ≥ −12 dB, and severe ≤ −12 dB.

Corneal Hysteresis Measurements

Measurements of CH and CRF were acquired at the baseline visit and endpoint visit using the ORA (ORA Hardware Version 1.3, Software Version 5.0; Reichert Technologies Inc., Depew, N.Y.). ORA testing was performed by a trained technician. Further details of ORA measurement have been previously described.1 Briefly, a continuous jet of air is applied to the cornea to deform inward into a slight concavity with increasing air pressure (first application point), then with decreasing air pressure the cornea returns (past the second application point) to its original position. During this time, an optical sensor concurrently measures the deflection of the cornea at the first and second application points and records the air pressure used at each point as 2 peaks. The difference in pressure between these 2 peaks, measured in mm Hg, is termed CH. CRF is derived similarly as a combination of the 2 pressure measurements. The device provides a waveform score to determine measurement reliability, and a waveform score of > 3.5 was used for inclusion for analysis. The average waveform score of all measurements was 6.60. The highest waveform in each visit was used for analysis.

Statistical Analysis

Continuous and categorical data are presented as mean [95% confidence interval (CI)] and count (%). The evaluation of the effect of CH measurements on rates of visual field MD progression was performed using linear mixed models with random intercepts and random slopes. The model can account for the fact that different eyes can have different rates of retinal nerve fiber layer loss over time, while also accommodating correlations between both eyes of the same individual. Interaction terms between time and putative predictors can be included in the model as fixed factor to test whether there is a significant effect of the putative predictor on changes of the outcome variable over time. Several different predictors were investigated in this study, including baseline age, race (African American vs. non-African American), sex, mean IOP during the follow-up period, CCT, baseline CRF, CRF change, baseline CH and CH change as fixed effects and patient as a random effect. Age, race, and factors with borderline significant association (P < 0.1) in the univariable analysis were included in a multivariable model. All statistical analyses were performed with R (Version 3.6.1). The alpha level (type I error) was set at 0.05.

RESULTS

There were 72 eyes from 48 subjects with a mean age of 68.1 years (95% CI: 65.2-71.0), and subjects were followed on average for 4.5 years (95% CI: 4.5-5.4). Eyes excluded from this group were 14 with low waveform score with ORA, 6 with history of trabeculectomy, 3 with absence of glaucomatous optic neuropathy. A total of 31 eyes were classified as glaucoma suspects and 41 eyes were classified as glaucomatous eyes with 29 mild, 6 moderate, and 6 severe. Patients were also on topical therapy: 61 eyes on a prostaglandin, 22 eyes on a beta-blocker, 35 eyes on a carbonic anhydrase inhibitor, and 22 eyes on brimonidine. In addition, 8 eyes were not on drop therapy, 16 eyes were on single drop therapy, and 48 eyes were on multiple drop therapy. Table 1 shows the demographics and baseline characteristics of eyes included in this study. The included eyes had a mean of 7.3 (95% CI: 6.7-7.9) visual field tests.

The mean VF MD was −3.27 dB (95% CI: −4.73 to −1.81) at the baseline and progressed with a mean rate of −0.44 dB/year (95% CI: −0.63 to −0.24) over time. The mean baseline CH was 9.0 mm Hg (95% CI: 8.6-9.4) and the endpoint CH was 9.0 mm Hg (8.6-9.3) for a mean difference in CH of 0 (95% CI: −0.3 to 0.2), which was not significant (P = 0.826). The mean baseline CRF was 9.3 mm Hg (95% CI: 8.8-9.9) and the endpoint CRF was 9.2 mm Hg (8.6-9.8) for a mean difference in CRF of −0.1 (95% CI: −0.4 to 0.3), which was not significant (P = 0.701).

Table 2 shows the association of each putative factor on VF MD progression over time using linear mixed modeling. A lower baseline CH (P = 0.047) and decreasing CRF (P = 0.012) over time were associated with VF MD progression in univariable model (Fig. 1). No significant associations were found between baseline CRF or CH change with VF MD progression, respectively.

Age, race, mean IOP during follow-up time, CRF change, and baseline CH were then analyzed versus MD slope in a multivariable mixed model (Table 2). Accounting for confounding variables, lower baseline CH (P = 0.007) and decreasing CRF (P = 0.042) were still associated with a faster rate of VF MD loss during follow-up. Each 1 mm Hg lower baseline CH and decrease in CRF over time were associated with a 0.12 and 0.14 dB/year faster rate of VF MD loss, respectively, in the multivariable model. Approximately 20.6% (R²) of the variability in VF MD progression rates was explained by this model. In a stratified analysis of glaucoma suspect eyes and glaucomatous eyes,
**TABLE 1. Demographics and Characteristics of Study Population**

| Parameter                  | Glaucoma Suspect (N = 31 Eyes, 10 Subjects) | Glaucoma (N = 41 Eyes, 38 Subjects) | Overall (N = 72 Eyes, 48 Subjects) | P       |
|-----------------------------|---------------------------------------------|-------------------------------------|------------------------------------|---------|
| Baseline age, y             | 66.3 (60.8, 71.7)                           | 68.6 (65.2, 72.0)                   | 68.1 (65.2, 71.0)                  | 0.513   |
| Sex: female/male, n         | 8/2                                         | 18/20                               | 26/22                              | 0.084   |
| Race: African American/     | 3/7                                         | 7/31                                | 10/38                              | 0.414   |
| non-African American, n     |                                             |                                     |                                    |         |
| Follow-up time (ORA), y     | 4.5 (4.5, 4.5)                              | 4.5 (4.5, 4.5)                      | 4.5 (4.5, 4.5)                     | 0.955   |
| Follow-up time (VF), y      | 4.4 (4.0, 4.7)                              | 4.4 (4.1, 4.8)                      | 4.4 (4.1, 4.7)                     | 0.563   |
| Number of VF, n             | 7.1 (6.5, 7.7)                              | 7.4 (6.9, 8.0)                      | 7.3 (6.7, 7.9)                     | 0.103   |
| Baseline VF 24-2 MD, dB     | −0.41 (−2.41, 1.58)                         | −5.26 (−6.95, −3.56)                | −3.27 (−4.73, −1.81)               | <0.001  |
| MD slope, dB/year           | −0.28 (−0.56, −0.00)                        | −0.54 (−0.77, −0.30)                | −0.44 (−0.63, −0.24)               | 0.144   |
| CCT, µm                     | 551.3 (537.1, 565.4)                        | 536.0 (523.0, 548.9)                | 542.2 (530.0, 554.3)               | 0.031   |
| Mean IOP during follow-up   | 16.5 (15.3, 17.6)                           | 16.1 (15.1, 17.2)                   | 16.3 (15.3, 17.2)                  | 0.619   |
| Baseline CH, mm Hg          | 9.3 (8.7, 9.9)                              | 8.8 (8.3, 9.3)                      | 9.0 (8.6, 9.4)                     | 0.201   |
| Endpoint CH, mm Hg          | 9.5 (9.0, 10.0)                             | 8.6 (8.2, 9.0)                      | 9.0 (8.6, 9.3)                     | 0.006   |
| CH difference, mm Hg        | 0.2 (−0.2, 0.7)                             | −0.3 (−0.6, 0.1)                    | −0.0 (−0.3, 0.2)                   | 0.098   |
| Baseline CRF, mm Hg         | 9.6 (8.9, 10.3)                             | 9.1 (8.5, 9.7)                      | 9.3 (8.8, 9.9)                     | 0.260   |
| Endpoint CRF, mm Hg         | 9.8 (9.1, 10.6)                             | 8.8 (8.2, 9.4)                      | 9.2 (8.6, 9.8)                     | 0.027   |
| CRF difference, mm Hg       | 0.5 (−0.0, 0.9)                             | −0.4 (−0.9, −0.0)                   | −0.1 (−0.4, 0.3)                   | 0.008   |
| Disc hemorrhage, yes/no     | 3/28                                        | 10/31                               | 13/59                              | 0.107   |

Unless otherwise noted, values are mean (95% CI).

P values were calculated from comparison of glaucoma suspect and glaucoma groups.

P < 0.05 are shown as bold.

CCT indicates central corneal thickness; CH, corneal hysteresis; CRF, corneal resistance factor; IOP, intraocular pressure; MD, mean deviation; ORA, ocular response analyzer; VF, visual field.

**DISCUSSION**

Cornea hysteresis (CH) and CRF are biomechanical properties measured by the ORA with CH reflecting the viscoelastic properties of the cornea and CRF representing the elasticity and resistance of the cornea.12,13 In this study, although CRF and CH remained stable overall in the whole spectrum of glaucomatous eyes, a decrease in CRF over time as well as lower baseline CH were shown to be associated with faster visual field progression, even after adjusting age, race, and mean IOP. This suggests that the importance of tracking biomechanical changes when monitoring for glaucomatous progression.

CH and CRF have been hypothesized to be surrogate markers for glaucoma.14–16 Our findings of lower baseline CH associated with worsening visual fields is in line with that of previous studies.3,7 Lower baseline CH in particular has been shown to have a stronger association than thinner CCT for visual field progression over time although thinner CCT is associated more strongly

**TABLE 2. Glaucoma Suspect and Glaucomatous Eyes: Univariable and Multivariable Linear Mixed Model Analysis of the Effect of Various Factors on Mean Deviation Slope Over Time**

| Parameter                  | β (95% CI) | P       | β (95% CI) | P       |
|-----------------------------|------------|---------|------------|---------|
| Age (per 1 y older)         | 0.01 (−0.03, 0.01) | 0.188   | −0.01 (−0.03, 0.01) | 0.615   |
| Race (non-AA)               | −0.14 (−0.62, 0.34) | 0.569   | −0.14 (−0.59, 0.31) | 0.556   |
| Mean IOP during follow-up   | 0.05 (0.00, 0.11) | 0.073   | 0.03 (−0.02, 0.09) | 0.22    |
| (per 1 mm Hg higher)        |            |         |            |         |
| CCT (per 1 µm thinner)      | 0 (0.00, 0.01) | 0.736   |            |         |
| Baseline CH (per 1 mm Hg lower) | −0.11 (−0.22, 0.00) | 0.047   | −0.12 (−0.23, −0.01) | 0.042   |
| CH difference (per 1 mm Hg lower) | 0.04 (0.06, 0.015) | 0.419   |            |         |
| Baseline CRF (per 1 mm Hg lower) | 0 (0.09, 0.10) | 0.925   |            |         |
| CRF difference (per 1 mm Hg lower) | −0.13 (−0.23, −0.03) | 0.012   | −0.14 (−0.24, −0.04) | 0.007   |
| Baseline MD (per 1 dB lower) | 0 (−0.03, 0.03) | 0.875   |            |         |
| Disc hemorrhage             | −0.39 (−0.80, 0.02) | 0.070   |            |         |

Unless otherwise noted, values are mean (95% CI).

Coefficient β corresponds to the parameter’s effect on change over time. Negative values correspond to visual field deterioration over time and positive values correspond to visual field improvement.

P < 0.05 are shown as bold.

AA indicates African American; CCT, central corneal thickness; CH, corneal hysteresis; CRF, corneal resistance factor; IOP, intraocular pressure.
with a worse baseline visual field. Our study reflected this association in that glaucomatous eyes had a thinner CCT and worse baseline MD. However, in univariable and multivariable model analysis, lower baseline CH had a greater impact on MD slope. Although we found no correlation of CH change with visual field progression, the association of decreasing CRF with worsening visual field MD suggests the importance of outer tissue rigidity, especially when considered in comparison with viscous damping. Our longitudinal data supports Sullivan-Mee et al., who suggested that higher CRF as a protective factor. Less stiff scleral walls may be more prone to structural remodeling in settings of elevated IOP. The decrease in CRF possibly suggests a likewise decrease in scleral rigidity around the optic nerve head, thereby making it more susceptible for deformation and injury. Changes in the lamina cribrosa can be influenced by both the IOP and the cerebrospinal fluid pressure. The response of the structural integrity of the sclera to the translaminar gradient of IOP and cerebrospinal fluid pressures could possibly could possibly be associated with the deformation.

Factors which can longitudinally affect corneal biomechanics relevant to this study’s findings include age, IOP (both acute and chronic changes), and use of topical glaucoma drops. Both CRF and CH have been shown to decline with age in normal eyes. The physical characteristics of the cornea changes with age. Specifically, there is increased stiffness of the cornea as a result of increased cross linking of collagen fibers and increase in collagen fiber diameter. The increased stiffness results in less corneal elasticity. The magnitude of change in both CH and CRF is most significant when compared over lengthy periods of time. Hussain et al. conducted a large longitudinal study with a follow-up period ranging between 2 and 5 years on corneal hysteresis with 1418 normal and 322 POAG eyes. There was a decrease in CH of the POAG eyes of 0.11 mm Hg/year, which was significantly more than in normal eyes (0.07 mm Hg/year). This decrease in CH was maintained after adjustment for age and suggests other contributing factors in glaucomatous eyes.

Lower CH, thinner CCT, and higher mean IOP have been well documented to be associated with glaucoma. Prostaglandin agonists (PGA) have been shown to affect corneal hysteresis. No other topical glaucoma therapeutic agents have been reported with a similar finding and no prior studies have examined. Changes in the lamina cribrosa can be influenced by both the IOP and the effect of topical therapy on CRF. CH was found to increase after starting therapy in treatment naïve eyes. This CH change was also reversible in POAG eyes on chronic PGA after stopping and restarting in a span of 6 weeks. In our study, a linear regression model examined use of various topical glaucoma drops (PGA, beta blockers, carbonic anhydrase inhibitors, and alpha-2 agonists)
but no relationship was correlated with changes in CH or CRF (data not shown). Interpretation of this analysis was limited as patients were on chronic topical therapy started at various points of time before baseline ORA measurements were performed and, in some eyes, therapy was changed during the follow-up time.

There were limitations in this study. The size of the study population may not have been large enough to detect subtle changes in CH and CRF. In addition, the sample size was not large enough for stratified analysis between all stages of glaucoma. Although 4 years of follow-up time was appropriate, additional longitudinal study could provide more information as prior studies have confirmed age-related changes. Furthermore, as measurements were also done at baseline and at a later endpoint, additional measurements over a longer time period could establish rate of change with more precision. Of note, Moreno-Montanez et al.35 found that ORA measurements of CH and CRF are highly reproducible in normal and glaucomatous with an intraexaminer correlation coefficient of 0.93 and 0.84 for CRF and CH respectively. Alternatively, reproducibility of successive ORA measurements had a precision of 5.2% and 7.3% for CRF and CH, respectively.36 Although surgically treated glaucomatous eyes were excluded, the vast majority of eyes had some form of medical treatment, which can impact the interpretation of the stability of CRF and CH over time. A possible question arises about the natural progression of CH and CRF in untreated glaucomatous eyes especially when compared with normal eyes. Future studies directed at measuring CH and CRF before and after glaucoma surgery with longitudinal follow-up of visual field progression would provide further insight on the role of biomechanics in monitoring for glaucomatous progression.

In conclusion, the results of the present study showed that both baseline biomechanical properties of the cornea and their change over time are associated with visual field progression. In addition to routine measurement of IOP, clinicians should consider assessing corneal resistance and elasticity at baseline and during periodic follow-up examinations to identify those eyes at highest risk of visual field progression.

REFERENCES

1. Anderson DR, Drance SM, Schulzer M. Comparison of glaucomatous progression between untreated patients with normal-tension glaucoma and patients with therapeutically reduced intraocular pressures. Am J Ophthalmol. 1998;126:487–497.

2. De Moraes B. Risk factors for visual field progression in treated glaucoma. Arch Ophthalmol. 2011;129:562–568.

3. Susanna BN, Ogata NG, Jammal AA, et al. Corneal biomechanics and visual field progression in eyes with seemingly well-controlled intraocular pressure. Ophthalmology. 2019;126:1640–1646.

4. Heijl A, Leske MC, Bengtsson B, et al. Reduction of intraocular pressure and glaucoma progression. Evidence-Based Eye Care. 2003;4:137–139.

5. Gordon MO, Beiser JA, Brandt JD, et al. The ocular hypertension treatment study: baseline factors that predict the onset of primary open-angle glaucoma. Arch Ophthalmol (Chicago, Ill 1960). 2002;120:714–730.

6. Abitbol O, Bouden J, Doan S, et al. Corneal hysteresis measured with the ocular response analyzer & in normal and glaucomatous eyes. Acta Ophthalmol. 2010;88:116–119.

7. Medeiros FA, Meire-Freitas D, Lisboa R, et al. Corneal hysteresis as a risk factor for glaucoma progression: a prospective longitudinal study. Ophthalmology. 2013;120:1533–1540.

8. Zhang C, Tatham AJ, Abe RY, et al. Corneal hysteresis and progressive retinal nerve fiber layer loss in glaucoma. Am J Ophthalmol. 2016;166:29–36.

9. Susanna CN, Diniz-Filho A, Daga FB, et al. A prospective longitudinal study to investigate corneal hysteresis as a risk factor for predicting development of glaucoma. Am J Ophthalmol. 2018;187:148–152.

10. Sullivan-Mee M, Billingsley SC, Patel AD, et al. Ocular response analyzer in subjects with and without glaucoma. Optom Vis Sci. 2008;85:463–470.

11. Luce DA. Determining in vivo biomechanical properties of the cornea with an ocular response analyzer. J Cataract Refract Surg. 2005;31:156–162.

12. Shah S, Laiuzzaman M, Cunliffe I, et al. The use of the Reichert ocular response analyzer to establish the relationship between ocular hysteresis, corneal resistance factor and central corneal thickness in normal eyes. Contact Lens Anterior Eye. 2006;29:257–262.

13. Kotecha A, Elsheikh A, Roberts CR, et al. Corneal thickness and age-related biomechanical properties of the cornea measured with the ocular response analyzer. Investig Ophthalmol Vis Sci. 2006;47:5337–5347.

14. Wong BJ, Moghimis S, Zangwill LM, et al. Relationship of corneal hysteresis and anterior lamina cribrosa displacement in glaucoma. Am J Ophthalmol. 2020;212:134–143.

15. Terai N, Raiskup F, Haustein M, et al. Identification of biomechanical properties of the cornea: The ocular response analyzer. Curr Eye Res. 2012;37:553–562.

16. Girard MJ, Francis Suh J, Bottlang M, et al. Biomechanical changes in the sclera of monkey eyes exposed to chronic IOP elevations. Investig Ophthalmol Vis Sci. 2011;52:5656–5669.

17. Fazio MA, Clark ME, Bruno L, et al. In vivo optic nerve head mechanical response to intraocular and cerebrospinal fluid pressure: imaging protocol and quantification method. Sci Rep. 2018;8:1–11.

18. Tong J, Ghate D, Kedar S, et al. Relative contributions of intracranial pressure and intraocular pressure on lamina cribrosa behavior. J Ophthalmol. 2019. doi:10.1155/2019/3064949.

19. Hua Y, Voorhees AP, Sigal IA. Cerebrospinal fluid pressure: revisiting factors influencing optic nerve head biomechanics. Investig Ophthalmol Vis Sci. 2018;59:154–165.

20. Elsheikh A, Wang D, Brown M, et al. Assessment of corneal biomechanical properties and their variation with age. Curr Eye Res. 2007;32:11–19.

21. Elsheikh A, Wang D, Rama P, et al. Experimental assessment of human corneal hysteresis. Curr Eye Res. 2008;33:205–213.

22. Kida T, Liu JHK, Weinreb RN. Effects of aging on corneal biomechanical properties and their impact on 24-hour measurement of intraocular pressure. Am J Ophthalmol. 2008;146:567–572.

23. El Masry AAK, Said AA, Osman IM, et al. Corneal biomechanics in different age groups. Int Ophthalmol. 2020;40:967–974.

24. Rosa N, Lanza M, De Bernardo M, et al. Relationship between corneal hysteresis and corneal resistance factor with other ocular parameters. Semin Ophthalmol. 2015;30:335–339.

25. Sharifipour F, Panahi-hazaz M, Bidar R, et al. Age-related variations in corneal biomechanical properties. J Curr Ophthalmol. 2016;28:117–122.

26. Hussain SA, Alseberje JB, Ehrlich JR, et al. Change in corneal hysteresis over time in normal, glaucomatous and diabetic eyes. Acta Ophthalmol. 2015;93:e627–e630.

27. Doughty MJ, Zaman ML. Human corneal thickness and its impact on intraocular pressure measures: a review and meta-analysis approach. Surv Ophthalmol. 2000;44:367–408.

28. Oestreicher F, Weinreb RN, Zangwill LM, et al. Long-term intraocular pressure fluctuations and risk of conversion from ocular hypertension to glaucoma. Ophthalmology. 2008;115:934–940.

29. Kaushik S, Pandav SS, Banger A, et al. Relationship between corneal biomechanical properties, central corneal thickness, and intraocular pressure across the spectrum of glaucoma. Am J Ophthalmol. 2012;153:840–849.
30. Ang GS, Bochmann F, Townend J, et al. Corneal biomechanical properties in primary open angle glaucoma and normal tension glaucoma. *J Glaucoma*. 2008;17:259–262.

31. Sun L, Shen M, Wang J, et al. Recovery of corneal hysteresis after reduction of intraocular pressure in chronic primary angle-closure glaucoma. *Am J Ophthalmol*. 2009;147:1061–1066.e2.

32. Agarwal DR, Ehrlich JR, Shimmyo M, et al. The relationship between corneal hysteresis and the magnitude of intraocular pressure reduction with topical prostaglandin therapy. *Br J Ophthalmol*. 2012;96:254–257.

33. Bolivar G, Sánchez-Barahona C, Teus M, et al. Effect of topical prostaglandin analogues on corneal hysteresis. *Acta Ophthalmol*. 2015;93:e495–e498.

34. Meda R, Wang Q, Paoloni D, et al. The impact of chronic use of prostaglandin analogues on the biomechanical properties of the cornea in patients with primary open-angle glaucoma. *Br J Ophthalmol*. 2017;101:120–125.

35. Moreno-Montañés J, Maldonado MJ, García N, et al. Reproducibility and clinical relevance of the ocular response analyzer in nonoperated eyes: corneal biomechanical and tonometric implications. *Investig Ophthalmol Vis Sci*. 2008;49:968–9740.

36. Kopito R, Gaujoux T, Montard R, et al. Reproducibility of viscoelastic property and intraocular pressure measurements obtained with the ocular response analyzer. *Acta Ophthalmol*. 2011;89:225–230.