

Corneal Hysteresis and Visual Field Asymmetry in Open Angle Glaucoma

Aashish Anand,¹ Carlos Gustavo V. De Moraes,^{1,2} Christopher C. Teng,^{1,2,3} Celso Tello,^{1,3} Jeffrey M. Liebmann,^{1,2} and Robert Ritch^{1,3}

PURPOSE. To investigate the association between corneal biomechanical parameters and asymmetric primary open angle glaucoma (POAG) using the Ocular Response Analyzer (ORA).

METHODS. In a prospective cross-sectional study, ORA parameters were measured in 117 POAG patients with asymmetric visual fields (VF). The asymmetry in VF was defined as a five point difference between the eyes using the Advanced Glaucoma Intervention Study (AGIS) scoring system. Subjects with previous intraocular or refractive surgery, ocular comorbidities and diabetes were excluded.

RESULTS. In worse eyes, mean AGIS scores were significantly higher (8.1 ± 4.3 vs. 1.0 ± 1.6 ; $P < 0.001$) and mean corneal hysteresis (CH) was significantly lower (8.2 ± 1.9 vs. 8.9 ± 1.9 mm Hg; $P < 0.001$). Median ORA-corrected intraocular pressure was higher in the worse eyes (IOP_{cc}, 17.4 mm Hg vs. 16.9 mm Hg; $P < 0.001$). Worse eyes had a slightly lower mean corneal resistance factor ($P = 0.04$) and more myopic mean spherical equivalent ($P = 0.02$). No difference was seen in the central corneal thickness (CCT; $P = 0.63$) and Goldmann applanation tonometry (GAT; $P = 0.32$). On multivariate analysis, only CH retained an association with the worse eye (odds ratio, 25.9; 95% confidence interval, 10.1–66.5). ROC curves showed that only CH and IOP_{cc} had a discriminative ability for the eye with worse VF (AUC, 0.82 and 0.70, respectively).

CONCLUSIONS. Asymmetric POAG was associated with asymmetry in ORA parameters but not in CCT and GAT. Lower CH was associated with worse eyes independently of its effect on IOP measurement and had the best discriminability for the eye with the worse VF. (*Invest Ophthalmol Vis Sci*. 2010;51:6514–6518) DOI:10.1167/iovs.10-5580

Patients with primary open angle glaucoma (POAG) often have asymmetric visual field (VF) damage or field loss limited to one eye. The percentage of normal tension (NTG) and high tension glaucoma (HTG) patients with unilateral VF

loss has been estimated to be approximately 25% to 35%.¹ Although some studies have found a higher frequency of unilateral VF loss in NTG compared with HTG on kinetic perimetry, others have found no differences on automated static perimetry.^{1,2}

Mechanisms both dependent on and in addition to intraocular pressure (IOP) have been implicated in attempts to explain this asymmetry. Although some studies have found an association between asymmetric IOP and asymmetric VF,^{1,3,4} a randomized controlled trial found no relationship between mean, peak, trough, and peak minus trough IOP with VF asymmetry in NTG patients.⁵ More recently, postural asymmetry in IOP and asymmetric IOP responses to the water drinking test have been associated with asymmetric VF loss.^{6,7} Asymmetric central corneal thickness (CCT) was associated with asymmetric POAG in a retrospective study.⁸ In a later study by the same group, however, asymmetric POAG was associated with asymmetric dynamic contour tonometry (DCT) but not Goldmann applanation tonometry (GAT) or CCT.⁹ The evidence suggesting asymmetry in retrobulbar and internal carotid artery blood flow velocities in OAG patients with asymmetric VF is conflicting.^{10–13}

The Ocular Response Analyzer (ORA; Reichert, Inc., Depew, NY) measures two corneal biomechanical parameters—corneal hysteresis (CH) and corneal resistance factor (CRF)—and provides a measure of IOP that is corrected for these parameters. CH represents “viscous damping” in the corneal tissue.^{14,15} Glaucoma patients have been reported to have lower than normal CH, and lower hysteresis has been associated with VF progression.^{14,16–18}

In this study, we compared CH, CRF, and corneal compensated IOP (IOP_{cc}) between paired eyes in asymmetric POAG. Our purpose was to evaluate the association of ORA parameters with the worse eye in asymmetric POAG compared with other glaucoma risk determinants.

SUBJECTS AND METHODS

Subject Selection

In a prospective cross-sectional study, patients seeking treatment at a glaucoma practice over a 3-month period were screened to identify those with open angles and unilateral or asymmetric VF defects. Exclusion criteria were secondary glaucoma, unreliable VF, previous intraocular surgery, and conditions with known or anticipated effect on ORA measurement, including diabetes mellitus, keratorefractive surgery, rigid contact lens use, and corneal scarring. Laser trabeculoplasty was not an exclusion criterion as long as it was performed in both eyes within 6 months of each other and no laser procedure was performed in the preceding 3 months ($n = 15$). In compliance with the Declaration of Helsinki, the study was approved by the Institutional Review Board of the New York Eye and Ear Infirmary.

From the ¹Einhorn Clinical Research Center, New York Eye and Ear Infirmary, New York, New York; ²Department of Ophthalmology, New York University School of Medicine, New York, New York; and the ³Department of Ophthalmology, New York Medical College, Valhalla, New York.

Presented in part at the annual meeting of the American Glaucoma Society, Naples, Florida, March 5, 2010.

Supported in part by the James Cox Chambers Research Fund of the New York Glaucoma Research Institute, New York, NY and the Glaucoma Research and Education Fund of Lenox Hill Hospital, New York, NY (CGVM).

Submitted for publication March 24, 2010; revised May 17, 2010; accepted June 15, 2010.

Disclosure: **A. Anand**, None; **C.G.V. De Moraes**, None; **C.C. Teng**, None; **C. Tello**, None; **J.M. Liebmann**, None; **R. Ritch**, None

Corresponding author: Carlos Gustavo V. De Moraes, Research Assistant Professor, New York Eye and Ear Infirmary, 310 East 14th Street, New York, NY 10003; gustavonyee@gmail.com.

Visual Fields

VF testing was performed with a static, automated, achromatic perimetry (24-2 test pattern, Mk II, model 750; Carl Zeiss Meditec, Inc., Dublin, CA) using the SITA-standard program. Each VF was scored using the Advanced Glaucoma Intervention Study (AGIS) II numeric scoring system,¹⁹ which generates a numerical score of 0 to 20, where 0 equates to no VF loss, 1 to 5 to mild loss, 6 to 11 to moderate loss, 12 to 17 to severe loss, and 18 to 20 to end-stage VF loss. For this study, unilateral VF loss was defined as an AGIS score of 0 in the better eye and an interocular score asymmetry of 5 or greater. Asymmetric VF loss was defined as AGIS score of 5 or less in the better eye and an interocular score asymmetry of 5 or greater.

Measurement of ORA Parameters

Corneal biomechanical properties were measured using the ORA. Details of the technology have been previously described.¹⁴ The observer was masked to the asymmetry in visual fields. Three good quality measurements were taken, and the best waveform reading as selected by the computer software was used to eliminate selection bias. A good quality reading was defined as one with a symmetrical height of force-in and force-out waveform peaks and a waveform score (WS) of >5 in a software-generated scale of 0 to 10.^{14,20} All readings were taken between 8:00 AM and 3:00 PM.

Clinical Data

Demographic details and clinical data, including diagnosis, duration of follow-up, GAT, CCT, ocular medications, refractive error, and global indices from the qualifying VF, were extracted from the electronic medical records. The CCT for each eye was obtained by averaging three ultrasonic pachymetry (DGH-550 Pachette 2; DGH Technology, Exton, PA) readings within 5 μm of each other.

Statistical Analysis

Asymmetry ≥0.5 mm Hg in CH, ≥1 mm Hg in IOP, and ≥10 μm in CCT between the worse and better eye was defined as clinically

significant.^{3-5,8,21,22} A sample size of more than 110 patients was calculated to have a statistical power of 90% for detecting asymmetry in CH and a power of 80% for detecting asymmetric IOP and CCT, controlling the probability of a type 1 error at 0.05.

Data were analyzed using statistical software (SPSS version 11; SPSS Inc., Chicago, IL). Categorical data were compared using χ^2 tests. Continuous variables were tested for normal distribution. Variables with normal distribution are presented as mean ± SD and were compared using Student's paired *t*-test. Variables with skewed distribution are presented as median with interquartile range (IR) and were compared using Wilcoxon signed-rank tests. Univariate and multivariate odds ratios were calculated for ORA parameters and other glaucoma risk factors. Pearson correlation coefficients were used to determine correlation of various parameters with the AGIS scores. Receiver operating characteristic (ROC) curves were plotted for ORA and other glaucoma risk factors. Area under the curve (AUC) for each parameter was compared to determine the best predictor for the worse eye in POAG with asymmetric VF. A two-tailed *P* < 0.05 was considered statistically significant for all analyses.

RESULTS

We enrolled 117 patients (median age, 62.0 years; IR, 52.5-72.0 years) with asymmetric POAG. There were 66 (56.4%) men and 51 (43.6%) women. There were 74 (63.2%) Caucasian, 12 (10.3%) African American, 20 (17.1%) Asian, and 11 (9.4%) Hispanic subjects. Based on the study definitions, 72 (61.5%) patients had unilateral VF defects, whereas 45 (38.5%) had asymmetric VF defects. Mean follow-up of the study patients since their initial consultation was 4.4 ± 4.1 years (range, 5 months to 20 years).

Although CH and CCT were normally distributed, the IOP data (both GAT and IOP_{cc}) showed a skewed distribution in the study population (Fig. 1). Clinical and corneal biomechanical parameters in the worse and better eyes of study patients are compared in Table 1. Visual fields in the paired eyes were

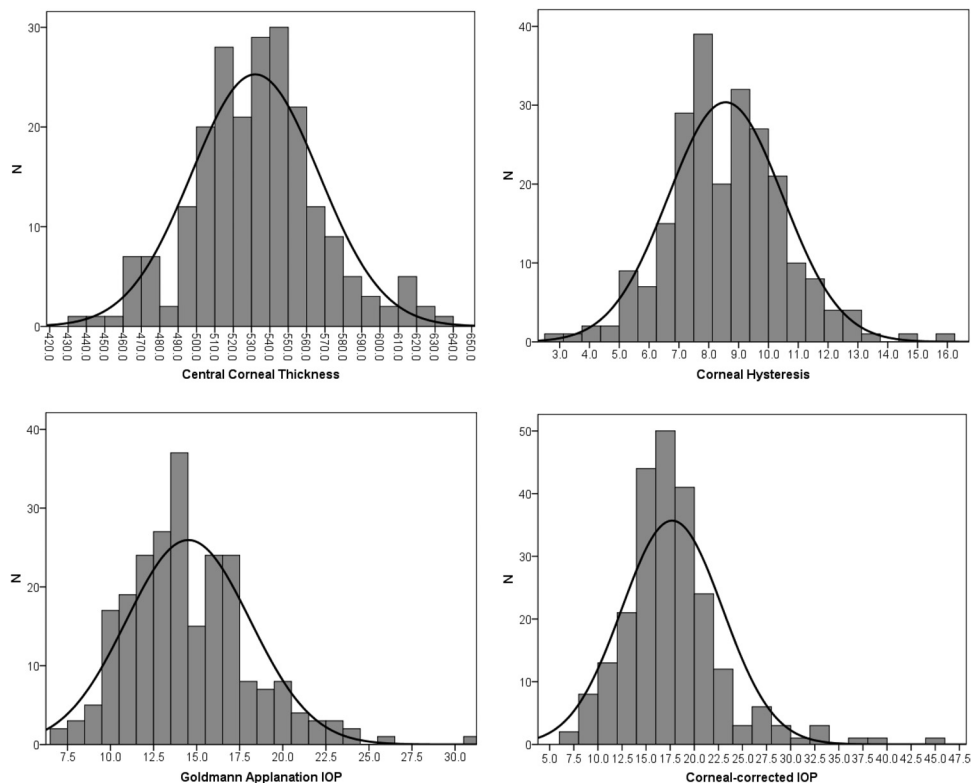


FIGURE 1. Distribution curves for CCT, CH, GAT, and IOP_{cc} in the study population.

TABLE 1. Interocular Comparison of Clinical Data in Patients with Asymmetric POAG

	Worse Eye	Better Eye	<i>P</i>
Visual Fields			
Global indices, dB			
MD	-11.2 ± 6.4	-2.1 ± 2.5	<0.001
PSD	9.6 ± 3.2	3.2 ± 2.3	<0.001
AGIS II numeric scoring			
VF scores	8.1 ± 4.3	1.0 ± 1.6	<0.001
Clinical Data			
Left eyes, <i>n</i> (%)	64 (54.7)	53 (45.3)	0.2
CCT, μ m	531.8 ± 34.7	532.3 ± 34.9	0.6
SE, diopters	-2.6 ± 3.7	-2.4 ± 3.8	0.02
GAT, mm Hg*	14 (12-17)	14 (12-16)	0.3
Drops	2.2 ± 0.9	2.1 ± 2.6	0.9
ORA Metrics			
CH, mm Hg	8.2 ± 1.9	8.9 ± 1.9	<0.001
CRF, mm Hg	8.6 ± 2.0	8.8 ± 2.1	0.04
IOP _{CC} , mm Hg*	17.4 (15.2-20.3)	16.9 (14.4-19.3)	<0.001

Data are presented as the mean ± SD unless otherwise noted. MD, mean deviation; PSD, pattern standard deviation; AGIS, AGIS numeric scoring for visual field.

* IOP data have skewed distributions and are presented as the median (IR).

significantly different in the mean AGIS scores and mean global indices. Worse eyes were associated with a lower mean CH (mean CH, 8.2 ± 1.9 mm Hg vs. 8.9 ± 1.9 mm Hg; *P* < 0.001) and a higher median corneal corrected ORA-IOP (median IOP_{CC}, 17.4 mm Hg vs. 16.9 mm Hg; *P* < 0.001). Mean corneal resistance factor (CRF) was significantly lower in the worse eyes (mean CRF, 8.6 ± 2.0 mm Hg vs. 8.8 ± 2.1 mm Hg; *P* = 0.04).

The median GAT measurement (median GAT, 14.0 mm Hg) was statistically similar in both eyes on a similar mean number of antiglaucoma drops (mean, 2.2 ± 0.9 vs. 2.1 ± 2.6; *P* = 0.9). GAT measurements were equal in the worse and better eyes in 41 (35%) patients. Antiglaucoma drops in the worse and better eyes were not significantly different with regard to the use of prostaglandins (89.1% vs. 82.9%; *P* = 0.2), β -blockers (55.9% vs. 48.6%; *P* = 0.3), carbonic anhydrase inhibitors (47.7% vs. 42.3%; *P* = 0.4), α -agonists (13.2% vs. 16.6%; *P* = 0.2), and cholinergics (3.8% vs. 2.1%; *P* = 0.3).

Although not statistically significant, the left eye was more frequently the worse eye (left eye, 55% worse eye vs. 45% better eye; *P* = 0.2). However, no significant difference was seen in the mean CH of the right and left eyes (mean CH, 8.5 ± 1.9 vs. 8.6 ± 1.9 mm Hg; *P* = 0.9). Worse eyes were mildly but significantly more myopic than the better eyes (mean spherical equivalent [SE], -2.6 ± 3.7 diopters vs. -2.4 ± 3.8 diopters; *P* = 0.02). There was no asymmetry in the mean CCT between the worse and better eyes (mean CCT, 531.8 ± 34.7 μ m vs. 532.3 ± 34.9 μ m; *P* = 0.6).

On univariate analysis, worse eyes had higher odds of lower CH (odds ratio [OR], 16.7; 95% confidence interval [CI], 8.8-31.8), lower CRF (OR, 1.9; 95% CI, 1.1-3.2), and higher IOP_{CC} (OR, 3.2; 95% CI, 1.1-9.3). However, odds were similar for higher GAT (OR, 0.9; 95% CI, 0.5-1.3), lower CCT (OR, 1.0; 95% CI, 0.6-1.8), and more myopic SE (OR, 1.4; 95% CI, 0.8-2.4). On multivariate analysis using the three ORA parameters as covariates, worse eyes were only associated with a lower CH (OR, 25.9; 95% CI, 10.1-66.5; Fig. 2).

AGIS visual field scores correlated negatively with CH (*r* = -0.29; *P* = 0.01) and CRF (*r* = -0.18; *P* = 0.05) and positively with IOP_{CC} (*r* = 0.16; *P* = 0.05). Among all ORA parameters,

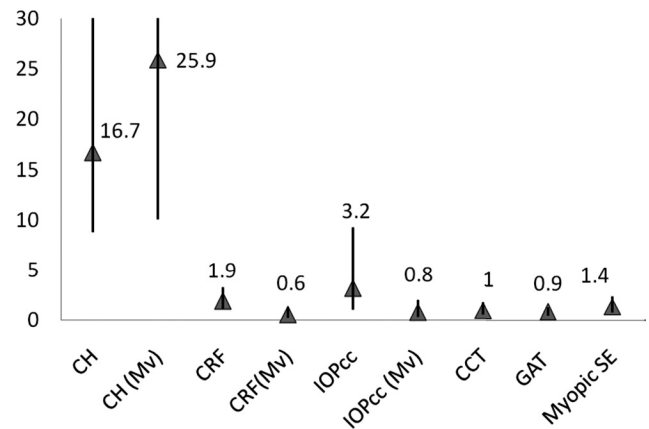


FIGURE 2. Univariate and multivariate odds ratios of ORA parameters and other glaucoma risk determinants for worse eye in asymmetric OAG. Mv, multivariate odds ratio (presented for variables found significant on univariate analysis).

CH showed the strongest, albeit a weak, correlation with the AGIS scores (Fig. 3). There was no correlation between AGIS scores and GAT (*r* = 1.0; *P* = 0.7), CCT (*r* = -0.08; *P* = 0.2), and SE (*r* = 0.03; *P* = 0.6). The difference in AGIS scores between the paired eyes (Δ AGIS score) did not correlate with the difference in CH (Δ CH; *r* = -0.038; *P* = 0.69), CRF (Δ CRF; *r* = 0.002; *P* = 0.98), and IOP_{CC} (Δ IOP_{CC}; *r* = 0.003; *P* = 0.97) between the eyes.

ROC curves of ORA parameters and other glaucoma risk factors for the worse eye in asymmetric POAG are shown in Figure 4. CH (AUC, 0.82; *P* < 0.001) and IOP_{CC} (AUC, 0.70; *P* < 0.001) were the only parameters with significant discriminative ability for the worse eye in asymmetric POAG. GAT and CCT asymmetry had poor discriminative ability for the worse eye (AUC, 0.52; *P* = 0.5; AUC, 0.48, *P* = 0.6, respectively).

DISCUSSION

Mean corneal hysteresis has been estimated to be between 9.6 mm Hg¹⁴ and 12.2 mm Hg²³ in a normal population. Lower

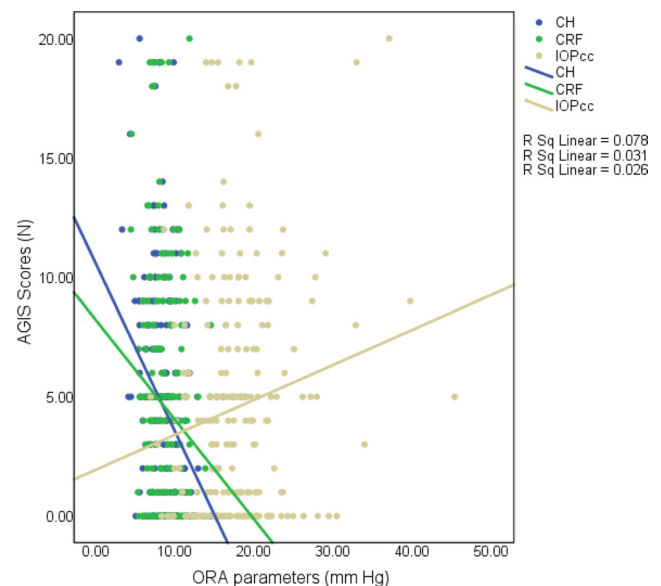


FIGURE 3. Scatter plot showing correlations between CH, CRF, and IOP_{CC} and AGIS visual field scores.

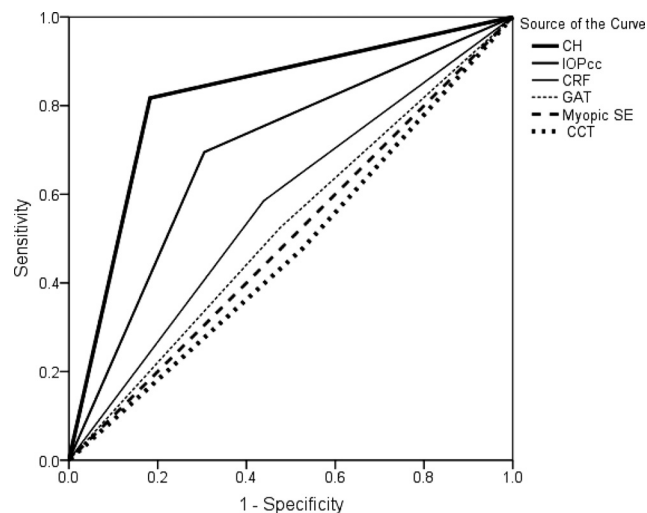


FIGURE 4. ROC curves (discriminability indices) of ORA parameters and other glaucoma risk factors for the worse eye in asymmetric OAG.

than normal CH has been associated with glaucoma and VF progression.¹⁶⁻¹⁸ In our study on asymmetric POAG, mean CH in both eyes was lower than normal mean CH reported in the literature. However, on a paired-eye comparison, 80% of the eyes with worse VF had even lower CH compared with the better eye. There was a mean difference of 0.7 mm Hg in the CH of worse and better eyes. Data are conflicting regarding asymmetric GAT-IOP in POAG patients with asymmetric VF.^{1,3-5} Sullivan-Mee et al.⁹ found higher DCT-IOP but similar GAT-IOP and CCT in asymmetric POAG. Both eyes in our study had a similar median GAT-IOP of 14 mm Hg. However, the corneal corrected ORA-IOP (IOP_{cc}) was 3 to 4 mm Hg higher than the GAT-IOP in both eyes, and an IOP asymmetry congruent with the asymmetry in VF was seen. Our results show that the GAT not only underestimates true IOP, but it may also underestimate asymmetry in IOP in patients with asymmetric POAG. However, our IOP comparison is based on a single daytime measurement and does not take nocturnal and diurnal variability in GAT-IOP into account. Nocturnal and postural IOP variability is clinically important in POAG patients.^{6,24,25}

Among CH, CRF, IOP_{cc}, GAT-IOP, CCT, and refractive error, we found that worse eyes had the strongest association with lower CH. The association between lower CH and worse eye remained strong even after adjusting for its effect on the corneal-corrected IOP on multivariate analysis. It has been speculated that the biomechanical characteristics of the cornea may reflect the biomechanical characteristics of the optic nerve head (ONH) complex. Lesk et al.²⁶ found that thicker corneas are associated with less compliant ONH. Bochmann et al.²⁷ have hypothesized an association between CH and lamina cribrosa biomechanics, independent of CCT, on finding a lower CH but similar CCT in glaucomatous eyes with acquired pit of the optic nerve. If this hypothesis is true, a simple explanation would be that the reduced viscous damping of the cornea, as represented by low CH, reflects increased deformability of the ONH complex. Under these circumstances, even a symmetric glaucomatous process would result in earlier and worse VF loss in the eye with lower CH. However, an experimental study found an association between higher CH and greater optic nerve deformation when IOP was artificially elevated in glaucomatous eyes.²⁸ Downs et al.²⁹ reported a change in the viscoelastic properties of peripapillary sclera on exposure to moderate, short-term, chronic IOP elevations in glaucomatous monkey eyes.

The strong association between lower CH and worse eyes does not necessarily establish a cause-and-effect relationship between hysteresis and extent of ON damage. In our study, CH had a weak negative correlation with AGIS scores, whereas Δ CH (CH in worse eye – CH in better eye) showed no correlation with Δ AGIS scores. It is possible that an association between lower CH and worse VF does not represent an inherent structural weakness of the eye but results from a simultaneous and independent change in the viscoelastic properties of the cornea and ONH complex by mechanical and nonmechanical glaucomatous processes. In such a case, asymmetric glaucomatous processes would lead to lower CH and worse VF in the more affected eye.

Kutchtey et al.³⁰ reported increased aqueous levels of angiopoietin-like 7 (ANGPTL7) protein by overexpression in the corneal stroma, sclera, and cribriform plates of lamina cribrosa in glaucomatous eyes. ANGPTL7 has been shown to increase the expression of proteoglycans and collagens types 1 and 5, and it is suspected that their increased expression can contribute to the pathogenesis of glaucoma by inducing collagen changes. Partial recovery of CH after successful IOP-lowering therapy in patients with unilateral chronic primary angle-closure glaucoma appears to support the hypothesis that corneal biomechanical properties are altered during glaucoma development.³¹ This hypothesis can also explain the inconsistency that though lower CH is associated worse visual fields, higher CH has been associated with increased compliance of the ONH. It is possible that the cornea and ONH may not respond identically to mechanical or nonmechanical stress.

Although animal studies have shown that ONH compliance decreases after an initial period of hypercompliance in experimental glaucoma,^{29,32} little is known about the long-term change in corneal compliance in glaucoma. Even though hysteresis was affected by individual components of elasticity, viscosity, and maximum stress in a mechanical model,³³ it remains to be determined whether raw values of corneal hysteresis can be compared with viscoelasticity/compliance of ONH measured using other methods. Despite a lack of clarity on the exact role of CH, it has the best discriminative index for worse eye in asymmetric OAG.

Our study sample had adequate power to bring out clinically significant asymmetry in CCT in asymmetric POAG. Despite CCT being an independent risk factor in VF progression,³⁴ our patients with asymmetric VF had similar mean CCT in both eyes. CCT measurements are highly symmetric in paired eyes in more than 93% of patients.^{21,35} Our results agree with an earlier finding of similar CCT in OAG patients with congruent asymmetry in VF and DAT-IOP.⁹ In our series, though the mean SE in worse eyes was mildly but significantly more myopic, worse eyes did not have an increased likelihood of greater myopia. Myopia has been associated with both glaucoma and low corneal hysteresis.^{36,37} Our results suggest that the association of myopia with the worse eye in asymmetric POAG may be confounded by its influence on the corneal viscoelastic properties. Some studies have found that left eyes have worse VF and mildly, but significantly, higher IOP in patients with asymmetric POAG.^{1,38,39} A higher number of left eyes in our series were also the worse eyes, though the association did not reach statistical significance. However, the mean CH of right and left eyes of our patients was almost identical.

In conclusion, asymmetric POAG is associated with asymmetric ORA parameters and corneal corrected IOP. Of these, CH has an independent association and the best discriminative index for the worse eye. However, this study was designed to evaluate association but not to establish causality between low CH and worse VF in asymmetric POAG. A cohort study with longer follow-up is required.

References

- Poinoosawmy D, Fontana L, Wu JX, Bunce CV, Hitchings RA. Frequency of asymmetric visual field defects in normal-tension and high-tension glaucoma. *Ophthalmology*. 1998;105:988-991.
- Levene RZ. Low tension glaucoma: a critical review and new material. *Surv Ophthalmol*. 1980;24:621-664.
- Cartwright MJ, Anderson DR. Correlation of asymmetric damage with asymmetric intraocular pressure in normal-tension glaucoma (low-tension glaucoma). *Arch Ophthalmol*. 1988;106:898-900.
- Levine RA, Demirel S, Fan J, et al. Asymmetries and visual field summaries as predictors of glaucoma in the ocular hypertension treatment study. *Invest Ophthalmol Vis Sci*. 2006;47:3896-3903.
- Greenfield DS, Liebmann JM, Ritch R, Krupin T, Low-Pressure Glaucoma Study Group. Visual field and intraocular pressure asymmetry in the Low-Pressure Glaucoma Treatment Study. *Ophthalmology*. 2007;114:460-465.
- Hong S, Kang SY, Ma KT, Seong GJ, Kim CY. Latent asymmetric intraocular pressure as a predictor of visual field defects. *Arch Ophthalmol*. 2008;126:1211-1215.
- Susanna R Jr, Hatanaka M, Vessani RM, Pinheiro A, Morita C. Correlation of asymmetric glaucomatous visual field damage and water-drinking test response. *Invest Ophthalmol Vis Sci*. 2006;47:641-644.
- Sullivan-Mee M, Gentry JM, Qualls C. Relationship between symmetric central corneal thickness and glaucomatous visual field loss within the same patient. *Optom Vis Sci*. 2006;83:516-519.
- Sullivan-Mee M, Halverson KD, Qualls C. Clinical comparison of Pascal dynamic contour tonometry and Goldmann applanation tonometry in asymmetric open-angle glaucoma. *J Glaucoma*. 2007;16:694-699.
- O'Brien C, Saxton V, Crick RP, Meire H. Doppler carotid artery studies in asymmetric glaucoma. *Eye*. 1992;6:273-276.
- Plange N, Kaup M, Arend O, Remky A. Asymmetric visual field loss and retrobulbar haemodynamics in primary open-angle glaucoma. *Graefes Arch Clin Exp Ophthalmol*. 2006;244:978-983.
- Breil P, Krummenauer F, Schmitz S, Pfeiffer N. The relationship between retrobulbar blood flow velocities and glaucoma damage: an intraindividual comparison. *Ophthalmologe*. 2002;99:613-616.
- Costa VP, Sergott RC, Smith M, et al. Color Doppler imaging in glaucoma patients with asymmetric optic cups. *J Glaucoma*. 1994;3:S91-S97.
- Luce DA. Determining in vivo biomechanical properties of the cornea with an ocular response analyzer. *J Cataract Refract Surg*. 2005;31:156-162.
- Moreno-Montañés J, Maldonado MJ, García N, Mendiluce L, García-Gómez PJ, Seguí-Gómez M. Reproducibility and clinical relevance of the ocular response analyzer in nonoperated eyes: corneal biomechanical and tonometric implications. *Invest Ophthalmol Vis Sci*. 2008;49:968-974.
- Congdon NG, Broman AT, Bandeen-Roche K, Grover D, Quigley HA. Central corneal thickness and corneal hysteresis associated with glaucoma damage. *Am J Ophthalmol*. 2006;141:868-875.
- Ang GS, Bochmann F, Townend J, Azuara-Blanco A. Corneal biomechanical properties in primary open angle glaucoma and normal tension glaucoma. *J Glaucoma*. 2008;17:259-262.
- Mangouritsas G, Morphis G, Mourtzoukos S, Feretis E. Association between corneal hysteresis and central corneal thickness in glaucomatous and non-glaucomatous eyes. *Acta Ophthalmol*. 2009;87:901-905.
- Advanced Glaucoma Intervention Study. 2: Visual field test scoring and reliability. *Ophthalmology*. 1994;101:1445-1455.
- Lam AK, Chen D, Tse J. The usefulness of waveform score from the Ocular Response Analyzer. *Optom Vis Sci*. In press.
- Hahn S, Azen S, Ying-Lai M, Varma R, Los Angeles Latino Eye Study Group. Central corneal thickness in Latinos. *Invest Ophthalmol Vis Sci*. 2003;44:1508-1512.
- Broman AT, Congdon NG, Bandeen-Roche K, Quigley HA. Influence of corneal structure, corneal responsiveness, and other ocular parameters on tonometric measurement of intraocular pressure. *J Glaucoma*. 2007;16:581-588.
- Laiquzzaman M, Bohjwani R, Cunliffe I, Shah S. Diurnal variation of ocular hysteresis in normal subjects: relevance in clinical context. *Clin Exp Ophthalmol*. 2006;34:114-118.
- Liu JH, Boulogny RP, Kripke DF, Weinreb RN. Nocturnal elevation of intraocular pressure is detectable in the sitting position. *Invest Ophthalmol Vis Sci*. 2003;44:4439-4442.
- Mosaed S, Liu JH, Weinreb RN. Correlation between office and peak nocturnal intraocular pressures in healthy subjects and glaucoma patients. *Am J Ophthalmol*. 2005;139:320-324.
- Lesk MR, Hafez AS, Descovich D. Relationship between central corneal thickness and changes of optic nerve head topography and blood flow after intraocular pressure reduction in open-angle glaucoma and ocular hypertension. *Arch Ophthalmol*. 2006;124:1568-1572.
- Bochmann F, Ang GS, Azuara-Blanco A. Lower corneal hysteresis in glaucoma patients with acquired pit of the optic nerve (APON). *Graefes Arch Clin Exp Ophthalmol*. 2008;246:735-738.
- Wells AP, Garway-Heath DF, Poostchi A, Wong T, Chan KC, Sachdev N. Corneal hysteresis but not corneal thickness correlates with optic nerve surface compliance in glaucoma patients. *Invest Ophthalmol Vis Sci*. 2008;49:3262-3268.
- Downs JC, Suh JK, Thomas KA, Bellezza AJ, Hart RT, Burgoyne CF. Viscoelastic material properties of the peripapillary sclera in normal and early-glaucoma monkey eyes. *Invest Ophthalmol Vis Sci*. 2005;46:540-546.
- Kuchtey J, Källberg ME, Gelatt KN, Rinkoski T, Komáromy AM, Kuchtey RW. Angiopoietin-like 7 secretion is induced by glaucoma stimuli and its concentration is elevated in glaucomatous aqueous humor. *Invest Ophthalmol Vis Sci*. 2008;49:3438-3448.
- 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.
- Burgoyne CF, Quigley HA, Thompson HW, Vitale S, Varma R. Early changes in optic disc compliance and surface position in experimental glaucoma. *Ophthalmology*. 1995;102:1800-1809.
- Glass DH, Roberts CJ, Litsky AS, Weber PA. A viscoelastic biomechanical model of the cornea describing the effect of viscosity and elasticity on hysteresis. *Invest Ophthalmol Vis Sci*. 2008;49:3919-3926.
- 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*. 2002;120:714-720.
- Brandt JD, Beiser JA, Kass MA, Gordon MO. Central corneal thickness in the Ocular Hypertension Treatment Study (OHTS). *Ophthalmology*. 2001;108:1779-1788.
- Mitchell P, Hourihan F, Sandbach J, Wang JJ. The relationship between glaucoma and myopia: the Blue Mountains Eye Study. *Ophthalmology*. 1999;106:2010-2015.
- Shen M, Fan F, Xue A, Wang J, Zhou X, Lu F. Biomechanical properties of the cornea in high myopia. *Vision Res*. 2008;48:2167-2171.
- Haefliger IO, Hitchings RA. Relationship between asymmetry of visual field defects and intraocular pressure difference in an untreated normal (low) tension glaucoma population. *Acta Ophthalmol (Copenh)*. 1990;68:564-567.
- Crichton A, Drance SM, Douglas GR, Schulzer M. Unequal intraocular pressure and its relation to asymmetric visual field defects in low-tension glaucoma. *Ophthalmology*. 1989;96:1312-1314.